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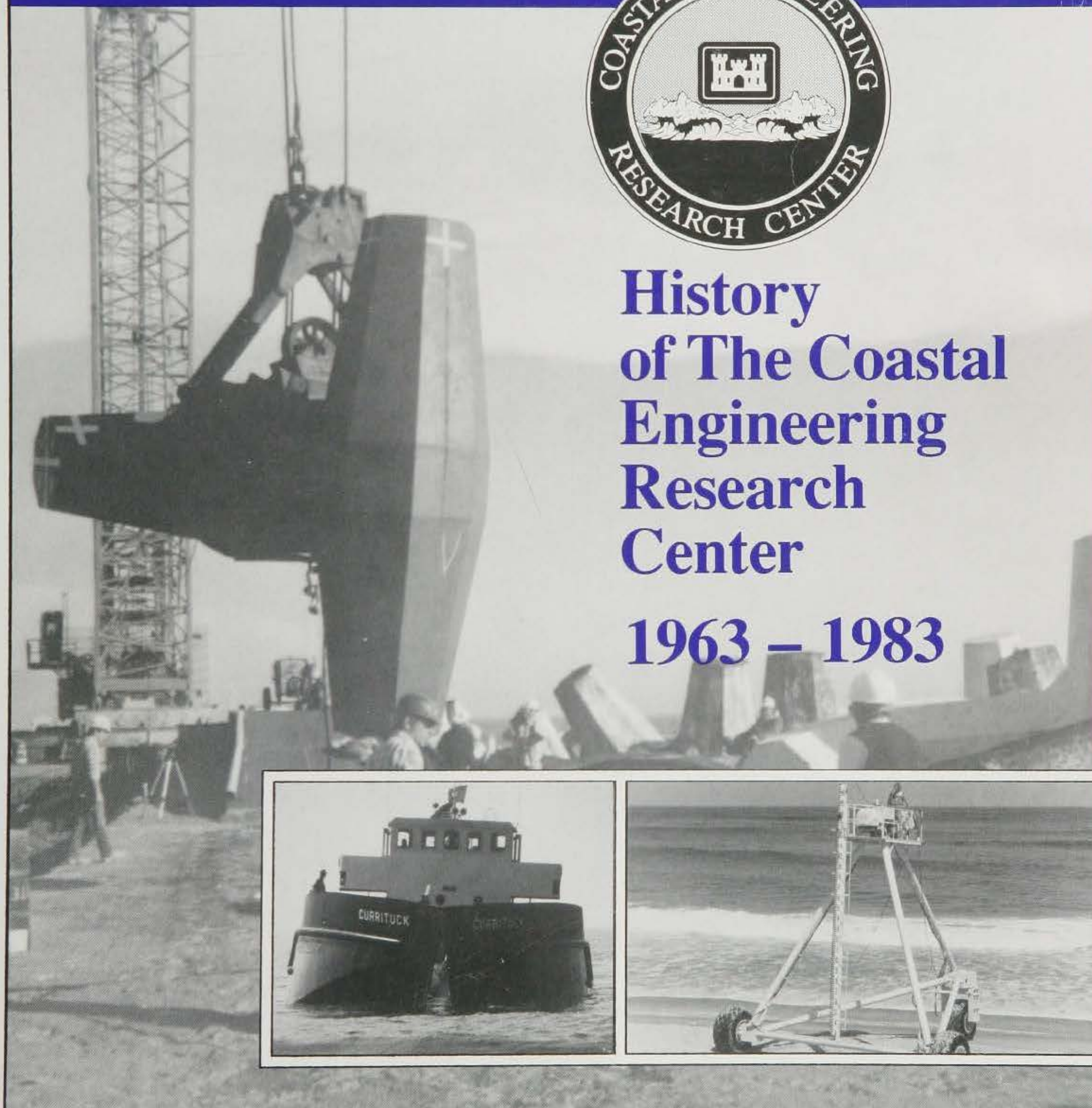
Volume I WES Laboratory History Series

COASTAL ENGINEERING RESEARCH CENTER

History of The Coastal Engineering Research Center 1963 – 1983



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HISTORY OF THE COASTAL ENGINEERING RESEARCH CENTER 1963 – 1983

Jamie W. Moore and Dorothy P. Moore

Vol I: WES Laboratory History Series

U.S. Army Engineer Waterways Experiment Station
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PREFACE

The *History of the Coastal Engineering Research Center, 1963 – 1983* launches a series of volumes being developed by the U.S. Army Engineer Waterways Experiment Station (WES) that will chronicle the programs and activities of its six laboratories. Subsequent books will trace the evolution of the remaining five – Hydraulics, Geotechnical, Structures, Environmental, and Information Technology – which collectively have built the station's reputation as a world-renowned research and development complex.

Over time the station's complement of scientists, engineers, and support personnel have conducted a broad array of engineering investigations, research, and development studies in support of both civil and military engineering. Since 1929, WES team members have blended scientific rigor, technical expertise, and common sense to better understand complex relationships between air, water, earth, structures, equipment, and living things. The products of these efforts are largely expressed in a rich tapestry of infrastructure that upholds the nation's prosperous economy, quality of life, strong defense, and commitment to environmental integrity.

This history discusses the pre-WES era of CERC, but it also introduces themes that will be carried forth in subsequent volumes of the WES Laboratory History Series. A boldness and healthy skepticism still permeates CERC and the other WES laboratories that help to challenge old assumptions and seek new frontiers of understanding. The following pages capture the institutional experience of CERC, a unique Federal asset responsive to changing needs and expectations by remaining on the cutting edge of inquiry and to solving problems – our mission.

LARRY B. FULTON
Colonel, Corps of Engineers
Commander and Director

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FOREWORD

Since its permanent establishment in 1802, the Corps of Engineers has been engaged in coastal engineering projects. Originally organized to design and build a coastal defense system and to supervise the U. S. Military Academy at West Point, the Corps first concentrated on constructing and maintaining strategically placed casemated fortifications to repel naval attack. Survey work and some harbor projects preceded the official acquisition of a civil works mission in 1824. For the rest of the 19th century, the Corps dealt with a variety of engineering problems unique to the coastal region.

When Congress created the Beach Erosion Board on 30 July 1930, the Corps began to investigate coastal engineering problems more formally. This role continued until 7 November 1963, when Congress created the Coastal Engineering Research Center and directed it to conceive, plan, and conduct research in the field of coastal engineering to provide better understanding of shore processes, winds, waves, tides, surges, and currents as they applied to navigation improvements, flood and storm protection, beach erosion control, and coastal engineering works.[1]

INTRODUCTION

When this study was first planned, the Coastal Engineering Research Center (CERC), a research facility of the U. S. Army Corps of Engineers, was located at Fort Belvoir, Virginia. By the time we began our work, the decision had been made to transfer CERC to the laboratory complex at the Waterways Experiment Station (WES). Because most of the professional staff at Fort Belvoir did not make the move, the transfer of CERC to Vicksburg, Mississippi, was, in effect, an organizational restructuring. The decision to relocate CERC was highly controversial. It is, of course, an important part of our story. One of the unfortunate consequences of the transition was the loss of nearly all of the CERC files at Fort Belvoir. We were obliged to rely on the personal records and memories of a number of people. To them go our heartfelt thanks. In particular, we are grateful to former CERC Technical Director Thorndike Saville, Jr., for the use of his extensive collection of private papers; to Dr. Robert W. Whalin, WES Technical Director, for his generous assistance; and to Dr. John Greenwood and the staff at the Office of History, Headquarters, U. S. Army Corps of Engineers.

The history of the Corps' involvement in coastal zone construction in the years prior to CERC's establishment divides naturally into three periods. During the first, running roughly from 1802 to 1900, the Corps, reflecting the values of an American society that saw nature as an obstacle to be overcome, proceeded with construction projects intended to aid navigation. The second period, which lasted from the turn of the century to 1936, was marked by political debates over the Federal responsibility for protecting people and property from the damaging effects of flooding. The third period was dominated by the Beach Erosion Board's (BEB's) transition to a research arm of the Corps.

The CERC's orientation reflects concerns that arose during the latter two stages. In the first stage, with the emergence of American industrial society, Progressives called for legislation to ensure a more active and responsible Federal Government. These reformers felt that the government should see that natural resources, including water, were managed wisely. From this beginning developed such concepts as planning of water resources projects for the multipurposes of navigation, flood control, irrigation, and electric power generation. The Progressives also felt that the Federal Government should build these projects because they were economically justifiable and important to National development. In time, in communities along the seacoasts, residents began to view coastal engineering projects in the same way.

To obtain more scientific and technical information, on 23 January 1929, the Chief of Engineers established a board of officers to investigate and report on sand movement and beach erosion. On 3 July 1930, Congress authorized the Corps to cooperate with appropriate state agencies in studying ways to prevent shore erosion. As a result, the Chief of Engineers, on September 18, terminated the Board on Sand Movement and Beach Erosion and appointed two new boards. One was the Shore Protection Board to investigate and report on the protection of Federal property. The second, created under Congressional authority, was a BEB to provide site-specific advice on combating erosion.[2]

Both the Corps and a private group, the American Shore and Beach Preservation Association (ASBPA), had worked to create the Beach Erosion Board. However, the two organizations had differing interests. The ASBPA hoped to obtain Federal financing for the construction of projects to protect coastal property owners from erosion. This did not occur. In 1936, Congress enacted legislation that

Beach Erosion Board Inspection Party, Cleveland, Ohio, 1940

established flood control as a Federal responsibility. Benefits would accrue to both public and private property owners, but the concept was not extended to the coastal zone.[3] In a parallel statute enacted four days later, Congress provided protection for only ocean shoreline property where a Federal interest was involved.[4]

The Beach Erosion Board was given two important tasks when it was established. One was to review plans for coastal projects where a Federal interest was involved for comment and approval prior to the authorization of any Federal funds. The other was to oversee — but not conduct — basic and applied research in the field of coastal zone engineering. Between 1936 and 1963, Federal policy concerning the coastal zone was eclectic. Because of the increasing costs involved in providing flood protection, Congressional support for protecting coastal property owners against erosion waned. Concurrently, the demonstrable needs of the rapidly growing coastal communities led the Federal government to push the Corps to become more involved in studying the scientific and technical problems of the seacoast. As a result, the Beach Erosion Board's dispassionate review of coastal problems evolved into a growing interest in conducting its own basic research.

In 1963, following an extensive review of the functions of both the Board of Engineers for Rivers and Harbors and the Beach Erosion Board, the Corps recommended replacing the BEB with a center for coastal engineering research. Several factors influenced the Corps' decision. They included a high regard for the past successes of the Beach Erosion Board, the implementation of Congressionally mandated planning, the challenge of expanding coastal zone missions authorized by Congress, and the need for better program coordination among the 22 Corps Districts bordering the coastline and engaged in some form of coastal process analysis.

Beyond all these concerns, the Office of the Chief of Engineers (OCE) wished to bolster the Corps' coastal research program to keep pace with the rapidly emerging national oceanographic program and to exploit anticipated opportunities. To enhance the status of coastal engineering research, the functions of the Beach Erosion Board were to be transferred to a coastal engineering research "center," as opposed to a Corps laboratory. As a center, CERC would operate directly under the Chief of Engineers. To retain the technical support of eminent civilian members of the Beach Erosion Board during the expansion, CERC would be guided by its own advisory committee, a Coastal Engineering Research Board (CERB). Coastal research programs would be coordinated at the level of the Director of Civil Works, and CERB would provide broad policy advice to the Chief of Engineers. The CERC would receive the bulk of its funding through a separate line item in the Corps budget. Through Congressional committee hearings, CERC would have direct access to the political process.[5]

In the last months of the BEB's existence, the staff laid down specific missions for CERC. In the main, all were based on the Corps' plans to expand the coastal research program. The tentative five-year program for Fiscal Years (FY) 1964-1968 presumed nearly a 50-percent increase in funding for coastal research, with annual budgets rising from $814,000 to $1,238,000. Projected ten-year coastal research expenditures, which included OCE programs, contemplated annual budgets ranging from $9,250,000 to $16,675,000. Later editions of the long-range planning process were even more ambitious. For the ten-year period 1966-1975, these proposed funding

increases from $1,100,000 in FY 1966 to a maximum of $5,000,000 in FY 1971 and staff increases from 76 to an estimated 131 people by FY 1970. This plan also called for meeting CERC's major physical property requirements in the near future, suggested ways to acquire such property, and foresaw additional purchases of equipment that might become necessary if work proceeded faster in some research areas than anticipated.

Research programs planned by the Coastal Engineering Research Center were divided into several categories. The major effort would be the assembly of an immense data bank of information about wave action and sediment transport. A simple and straightforward rationale lay behind the decision to collect and analyze enormous amounts of data. To design beaches and structures, one needs to be able to predict wave and sediment movement. This in turn requires knowledge about phenomena at a particular site. With a data bank of sufficient size and accuracy, CERC researchers could rapidly develop general, predictive theories. Designers then would be able to extract the information applicable to their specific engineering needs.

In the 1960s, the Corps responded to public and political interest in the coastal zone. Between 1964 and 1969, the Corps recommended increased CERC budgets, and Congress appropriated the funds. By 1968, funding for CERC research studies constituted 1.5 percent of the Corps' total coastal program budget even though the Corps' research program totaled between 0.5 and 0.6 percent of the Federal water resources program.

For most of this period, CERC was the only Federal agency with a coastal zone research mission and nearly alone in performing studies of waves and their effects. The CERC's strength lay in its promise of fulfilling the Corps' expectations that it could do more of what the Beach Erosion Board had been doing and do it better. The Office of the Chief of Engineers and the CERC staff believed basic research paid off even if immediate financial benefits could not be gaged; improved safety, convenience, and protection did not easily lend themselves to economic evaluation. Advocates claimed returns of 10 percent of program costs in the Corps' budget.

With this organizational image, the Coastal Engineering Research Center had begun its work. For slightly more than a decade, it prospered.

I

THE CORPS AND THE COASTAL ZONE, 1803-1963

Nineteenth Century Project Construction

Harbor and port development in the 19th century often depended on coastal engineering. Many harbors, usable in their natural state in the 18th century, had to be improved to admit the larger, steam-powered, ocean-going vessels of the industrial age. Local and Federal projects were designed to facilitate growth. Army engineers surveyed Baltimore Harbor in 1830, made recommendations, began a prolonged program of channel clearing in 1852 (in the summer of 1872 no fewer than 13 dredges were engaged in a mass excavation of waterways), and by the outbreak of the war with Spain in 1898 had transformed Baltimore into one of the world's major ports.[1]

Buffalo, located at the terminus of water and rail routes connecting the grain-rich areas of the West to the urban centers of the East, grew from a frontier village to a commercial and manufacturing center of nearly 600,000 in a little more than a century. During this entire period, the city's economic life depended on the construction and maintenance of harbor facilities. Seawalls, catch-sand piers (jetties), breakwaters, and dredging the formerly sand-clogged mouth of Buffalo Creek contributed to Buffalo's growth as one of the major cities on the Great Lakes. Cleveland similarly rose from a modest agricultural entrepot in the American heartland to a major industrial center as a result of successive harbor improvement projects.[2] Development of the California coast awaited construction of rail connections and harbors. When Congress in 1868 responded to requests for assistance, a long and productive period of Federal, State, and local cooperation began. Ultimately, it led to the development of modern, deepwater ports at Oakland, San Francisco, Los Angeles, and San Diego.[3]

Though statute, precedent, and organizational inclination focused the Corps' attention on navigation-related improvements, its activities in the coastal zone ranged from beach reconstruction to blasting better shipping channels to building new harbors. Work varied from region to region. In the 1820s, for example, for reasons no one could determine precisely, currents sweeping past Sullivan's Island, South Carolina, caused substantial erosion and threatened Fort Moultrie. Assigned to solve the erosion problems to existing fortification sites, the Corps initiated a major reclamation program.[4]

The first Corps project in New England was rebuilding a beach. In 1824, the Corps was assigned civil functions under the General Survey Act. In 1826, Congress voted appropriations for approximately 20 works and surveys. Under this authority, the Corps combated erosion by constructing cribwork breakwaters and arrested drifting sand by erecting brush fences and planting beach grass. Valuable spits of sand protecting Duxbury and Provincetown Harbors in Massachusetts were preserved by similar environmentally related projects. Sand piers, now called jetties, were built by the Army engineers at Warren River and Martha's Vineyard to catch sand carried by currents into the harbor.[5]

New York Harbor posed a different problem. At Hell Gate, a one-mile section of the East River that today runs from 90th to 100th Streets in Manhattan, where the river originally sliced around rocks and islands, turned sharply, met the Harlem River, and connected Long Island Sound with New York Harbor; the result was turbulent water generated because the tides in the harbor and sound do not coincide, but instead cause the waters to rush back and forth in ten-mile-per-hour currents. The city began a campaign to open up the East River in 1845. The Corps became involved in 1852 and for the next 30 years tackled the immensely difficult job of developing a new technology for underwater excavation and blasting to clear Hell Gate.[6]

Harbors not favored with natural channel cover were protected by building breakwaters. In New England, the Corps designed improvements at about two dozen localities. Included was the construction of the first wholly man-made harbor in the United States at Block Island, 12 miles off the Rhode Island coast, as a harbor of refuge.[7] Protection of a different sort was sought in the construction of the Galveston, Texas, seawall. Following a devastating storm in 1900, the city charged three engineers, one of whom was retired Chief of Engineers Brigadier General Henry M. Robert, to plan the safest and most efficient means to guard the city against ocean floods. Between October 1902 and July 1904, a 17,593-foot curved concrete wall was built with city and relief funds while Congress authorized a connecting seawall to protect the Federal investment in the port and military reservation at Fort Crockett.[8]

Nineteenth Century Engineering

Almost all engineering in coastal zones in the 19th century consisted of the practical application of principles well known to engineers accustomed to dealing with rivers. Little coastal engineering research was attempted. Concern about the unique nature of the coastal zone or studies of the effects of wind and water upon shores was sporadic, desultory, and unscientific. The first American book dealing specifically with coastal erosion was not published until 1913.[9]

Engineers learned much of their craft through trial and error. Innovations were not uncommon. An example was the improvement of the St. Johns River at Jacksonville, Florida, where a constantly shifting sinuous channel through the bar made navigation difficult. Beginning in the 1850s, Jacksonville citizens' groups had petitioned the Corps for aid in dealing with the sandbar that blocked the harbor entrance. Among the solutions proposed was putting the scouring power of the current to work by constructing jetties to project the channel through the bar. Corps engineers rejected this approach, but the best they could recommend was trying to deepen the channel by repeated dredging or raking during the strongest stage of the ebb current. Experiments with this technique failed miserably.

In the 1870s, influential citizens raised funds to bring Captain James Buchanan Eads to Jacksonville to study the problem. Eads had started out as a dry goods salesman. He then worked on steamboats, advancing to captain, became a contractor building ironclads for the U.S. government, and along the way learned a great deal about hydraulic engineering. In 1874, Eads had publicly challenged the Chief of Engineers' plan for improving navigation at the mouth of the Mississippi River. Eads claimed that he could design jetties that would do the job, and he capped his statement with an offer to construct the jetties at his own expense. He said the Federal Government would not have to pay him unless the project succeeded. When the government took Eads up on his offer, he built the jetties. They worked, and he gained national fame as a hydraulics engineer.

For Jacksonville, Eads recommended constructing two converging jetties to create a stable, deep channel out to sea. The report Eads wrote in 1878 contained principles of seacoast engineering, sketches of the tidal prism, and estimates of the areas that could be maintained. The report was far advanced for its time; the technology needed to conduct sophisticated studies that would confirm Eads' findings would not be available until well into the 20th century. Largely as a result of Eads' success, the Corps altered its recommendations for improving the St. Johns River, adopting a modified version of the Eads' plan for the jetties.[10]

At Charleston Harbor, South Carolina, Colonel Quincy Gillmore, familiar with Eads' plan for Jacksonville, employed a similar design. Here, between 1878 and 1893, the Corps constructed converging jetties that stretched outward from two barrier islands. The portions near the shores were built below the surface of the water, allowing the tide to come in normally. In the ebb tide, the bottom currents were channeled toward the bar and the parallel. Built higher, with the last quarter rising above sea level, the parallel directed the scouring force of the water against the sandbar and kept the new channel clear.[11]

Erosion Problem

From the earliest days of settlement, Americans continued building in the coastal zone. They placed structures to aid navigation, counter the effects of erosion, or protect backlands against storm surge. They designed seawalls, bulkheads, and revetments to establish and hold a line that would block the encroaching sea. The structures generally worked. Galveston and San Francisco seawalls are two examples. Other structures acted as barriers to the longshore transport of sand. Groins stabilized a finite section of beach. Jetties kept sand from building up in the area between them and served

navigation by stabilizing inlets, defining and maintaining harbor entrance channels, and providing calm water access to harbor terminals. The deliberate disruptions of natural processes were, to use the contemporary word, "improvements."[12]

Until the age of industrialization, the usual pattern was for people to settle inland, away from the ocean. Urbanization brought change. More affluent city-dwellers escaped to the seashore; there resort areas arose to accommodate them. These resorts remained isolated coastal enclaves tied to the hinterland by rails until the age of the automobile. Then beach-goers followed newly built roads to hotels, restaurants, boardwalks, and private vacation residences.[13]

As more people acquired a property interest in maintaining a fixed shoreline, concern over erosion grew. The most threatened area was in New Jersey, where landowners and public officials were alarmed by rapidly receding shoreline and the revenue loss to beach communities. In 1922, the State appropriated funds for a newly appointed Engineering Advisory Board on Coast Erosion (to report to the New Jersey State Board of Commerce and Navigation).

Investigations led to exchanges of information among experts who disagreed on the nature of the problem. Some said that because wind and wave velocity and other natural factors or construction-induced interruptions in the longshore transport of sand were the primary causes of erosion, engineers could find separate solutions to problems at specific sites. This claim presupposed that the "line" in shoreline meant something permanent. Other experts wondered if the relative positions of the land and sea were changing (some assumed that the sea was rising, others that the land was sinking, and still others both) and if the changes along the coast were long term, short term, or cyclical. If these were among the basic causes of erosion, the conclusion was that the more people built near the ocean, the greater the future losses would be. The advisory board reached no conclusions and recommended further research.[14]

In 1926, 85 delegates representing 16 states met at Asbury Park to discuss coastal zone problems. This meeting and two others held soon after led to the formation of the American Shore and Beach Preservation Association, an organization that brought together a cross section of engineers, public officials, State and Federal personnel, and property owners. Members saw themselves as educators and leaders in a conservation movement that would unite the states to fight a common enemy, the sea. The association's initial statement of purpose declared, "Man must come to the rescue of the beaches."[15]

In 1929, Senator Walter E. Edge of New Jersey introduced legislation to authorize Federal investigation of shore erosion problems. That same year, the Chief of Engineers established a board of four officers "to investigate and report on the subjects of sand movement and beach erosion at such localities as may be designated by the Chief of Engineers."[16] The Board on Sand Movement and Beach Erosion soon became known as the Sand Board. In the 1930 Rivers and Harbors Act, Congress gave the Chief of Engineers authority to make cooperative studies of the coast with appropriate agencies of coastal states. The Federal Government would pay half the costs.[17]

The Corps then created a seven-member Beach Erosion Board, with four members from the Corps, to furnish technical assistance, review investigation reports, and make first-hand observations. A Shore Protection Board, composed of the four military members of the Beach Erosion Board, was formed to

Beach Erosion at Cape May, New Jersey, 1935

investigate problems on Federal property relating to Federal coastal projects.[18]

As the wording of a 1929 special order creating the Sand Board suggests, the Corps at first was interested primarily in learning more about coastal processes. Dean Morrough P. O'Brien, who later would serve some 32 years on both the BEB and the board of the Coastal Engineering Research Center, was the first person hired. He knew nothing about shore processes. As he learned at his first meeting, that was what qualified him for the job. The board members had concluded that to formulate general theories they needed someone who was experienced in measurements but with no preconceived idea about shoreline phenomena. The board settled down in two experiment stations in Long Branch and Seaside Heights, New Jersey, and began to measure coastal zone processes.

The 1930 Rivers and Harbors Act authorizing the Corps to establish the Beach Erosion Board had a slightly different orientation. Under the terms of this act, the board was authorized to make investigations and studies "with a view to devising effective means of preventing erosion of the shores of coastal and lake waters."[19] The BEB was specifically asked to study problems at Rockaway Jetty, then proposed to protect New Jersey's Ambrose Channel.[20]

Murrough P. O'Brien

Federal Policy Changes

The powers of the Beach Erosion Board were limited. Members and staff soon found themselves in the difficult position of having to supply instant answers to problems that had not been investigated empirically. As the Depression worsened, efforts to involve government more actively in solving social problems intensified. Some New Deal advisors privately agreed that the Nation needed social planning on a scale similar to that of World War I military planning. New approaches to Federal water policy were among the proposals they suggested.[21] Groups representing communities threatened by periodic flooding worked diligently to capitalize on the rising public support for Federal initiatives.

The American Shore and Beach Preservation Association, representing threatened property owners and shore communities seeking quick Federal action to prevent further loss of the beaches, contended that the beaches were a public resource and should be treated as such. The association campaigned to extend legislation relating to river and harbor improvements to include shore protection. Their efforts were partially successful. In the Rivers and Harbors Act of 1935, Congress required the Corps to report on the effects proposed improvements at the mouths of rivers and coastal inlets would have on the beaches for ten miles in each direction.[22]

From the beginning, the Beach Erosion Board narrowly defined Federal responsibilities to protect private property. In general, the board reasoned that if local businessmen had placed their structures in dangerous locations to profit from the public demand for services, the Federal Government had no responsibility to bail them out. The idea of owner-induced liability and concomitant owner responsibility was not new to the Corps. Historically, the Corps had not favored Federal financing for protecting private property, whether in river basins or coastal flood plains. Chief of Engineers Major General Edgar Jadwin had initially recommended cost sharing for flood-control projects following the 1927 Mississippi River flood disaster.[23] Prior to the enactment of the 1936 flood-control statute, Chief of Engineers Major General Edward M. Markham opposed the language, subsequently incorporated in the act, that benefits "to whomsoever they accrue" would be calculated in determining the benefit-to-cost ratio because Federal expenditures would protect and enhance the value of private property.[24]

Some of the issues were resolved when Congress responded to a series of damaging floods by enacting the Flood Control Act of 22 June 1936. The measure established a national flood-control policy and defined protection from flooding as a proper activity of the Federal Government. Under the new legislation, the Federal Government, in cooperation with State and local communities, would improve or participate in the improvement of navigable waters for flood control if the benefits accruing from a project were greater than the construction costs.[25] Four days later Congress passed an "Act for the Improvement and Protection of Beaches Along the Shores of the United States." This was a more restrictive measure. In the coastal zone, Federal policy was to assist in the construction but not the maintenance of shore improvement and protection projects. A subsequent executive order fixed the maximum Federal financial participation at 50 percent of the total costs.[26]

Orientation Toward Research

The Federal responsibility for flood control grew rapidly. Between 1936 and 1952, approximately $11.1 billion was spent or allocated for flood-control purposes. Authorized and completed Corps projects during the period, few of which involved erosion control, exceeded $10 billion. To be sure, the 1936 Act for Improving and Protecting the Beaches had included many provisions desired by advocates of Federal protection for the coastal zone. However, the law stated that the Federal Government would assist in constructing coastal erosion control works where "Federal interests" were involved. What the term meant was not clear. One interpretation was that the Federal Government would pay for studies and investigations and 50 percent of project protection costs where a public interest could be demonstrated. Reflecting its prior conservatism, the Beach Erosion Board interpreted the statute literally, maintained tight limits on coastal construction, and continued to wait for requests from local governments before beginning investigations.[27]

Other Federal agencies, concerned with putting people to work, interpreted the 1936 act protecting beaches differently. Between April 1934 and July 1935, the Federal Emergency Relief Administration alone constructed 143 bathing beaches and improved 104 more. The Works Progress Administration built revetments, dikes, retaining walls, and jetties for flood control along North Carolina's Outer Banks at a cost of more than $4 million.[28] In 1937, contemplating more work of this nature, the National Resources Committee recommended a nationwide investigation of coastal erosion problems and called for comprehensive coastal development planning to be supervised by the Beach Erosion Board. In a message to Congress in 1936, President Roosevelt endorsed a six-year program of investigations costing $14.4 million.[29]

Because of the Beach Erosion Board's conservativism, requests for studies were sporadic and from widely separated communities. Moreover, the Corps held back on construction projects because surveys by the board revealed the uncertainty about predicting conditions at individual coastal sites. The interactions of natural phenomena, the cause of disappearing sand, and cyclical erosion and accretion were often matters of conjecture. Without more projects, coordinating the board's activities or integrating its work into a comprehensive study of the national erosion problem was impossible.[30]

Driven by professional curiosity about coastal processes, the Beach Erosion Board undertook scientific investigations despite the lack of explicit authorization in either the 1930 or 1936 acts. As a result of these investigations, the reports became more sophisticated over the years. Some incorporated findings from research conducted elsewhere; other studies took on the character of scientific treatises. Occasionally, a prescient Corps observer would caution that the history of accretion and erosion along the shore should figure in planning future development.[31] While these infrequent warnings usually fell on deaf ears, the board's knowledge grew steadily.

By the beginning of World War II, the board was publishing technical reports and memoranda on the results of its research, again an activity not specified in its charter. By then, too, the BEB had acquired a library and planned to expand its research facilities. The board's activities expanded during the war. Many in the Corps anticipated postwar public works programs, and the board's wartime successes convinced them that the BEB should have more authority to survey and investigate the coastal zone.[32]

Postwar Years

Memories of the Great Depression were vivid for government officials planning how to cushion the shock of converting from a wartime to a peacetime economy. A massive postwar public works program offered the opportunity to complete tasks that had been laid aside, provide employment, and stimulate

production. The Flood Control Act of 1944 thus authorized an unprecedented number of construction projects. Estimates of proposed expenditures exceeded $2.5 billion. Congressmen from the coastal areas, pointing out that approximately 70 percent of the new civil works program was to be paid by taxpayers in their states who stood to receive only 25 percent of the benefits from the projects, pushed through new coastal zone legislation.

In 1945, Congress authorized the Beach Erosion Board to make general investigations and publish studies and other data concerning erosion and beach protection. The board was to report on the "public interest" involved in a contemplated project rather than any "Federal interest," a change that broadened the areas where Federal assistance would apply. "Shores" were defined as including all the shorelines of the Atlantic and Pacific Oceans; the Gulf of Mexico; the Great Lakes; and lakes, estuaries, and bays directly connected. The board was empowered "to make general investigations with a view to preventing erosion of the shores of the United States by waves and currents and determining the most suitable methods for the protection, restoration, and development of beaches." The Federal Government would pay the cost of the investigations.[33]

In 1946, Congress approved Federal funding for up to one-third of the cost of new beach development and protection projects affecting public property. Congress also extended assistance in constructing flood-protection projects to ocean and lakefront municipalities comparable to that already guaranteed to communities affected by river flooding, and authorized Federal payment of up to one-third the cost of repairing seawalls built to protect major public highways.[34]

Despite the legislative changes, important factors still militated against any widespread Corps construction activity in the coastal zone. Members of the Beach Erosion Board continued to express a bias against piecemeal projects, favoring instead works that were large enough to protect an area such as headland to headland or inlet to inlet.[35]

This forced the large number of public agencies and local governments that usually were involved in any one project to try to reach agreement. Because the Federal funding for construction remained low, and as local interests continued to bear most of the construction and maintenance expenses, only a few projects were built. As Florida's Senator Claude Pepper pointed out, those that the BEB did approve (like the Harrison County, Mississippi, seawall) were projects of paramount public interest or exceptions to the general rule that local interests could not afford to finance the construction.[36]

Research and Development

The Beach Erosion Board's research program was intended to determine more effective and economical solutions to shore erosion control problems. Specific investigations, undertaken in cases where the results would have general application, were guided principally by the need for basic data dealing with waves, coastal sediment movement, and shoreline erosion. The BEB staff studied the generation of waves, tsunamis and tides; wave propagation; and wave transformation by refraction, diffraction, and energy dissipation in shallow coastal waters and at the shoreline. Studies of the movement of coastal sediments and their effect on shore stability involved research on the rate of supply of material and beach reactions to the littoral forces of waves, tides, currents, and wind.

Potentially effective measures to reduce shore erosion included structures, carefully designed and placed, and beach restoration using fill materials. Some studies were made in the laboratory, others in

Beach Erosion Board Field Team Near Long Branch, New Jersey, 1948

the field. Some work was done by the BEB staff, while other work was done under contract by universities having specialized equipment and personnel. Congressional funding, the primary source of money, varied. Appropriations were $350,000 in FY 1950, but over the next six years averaged only slightly more than $145,000. Research expenditures dropped from $210,000 in FY 1950 to $80,600 in FY 1951, when the BEB staff was shifted temporarily to military intelligence work at the outbreak of the Korean War. Fiscal Year 1952 basic research funding amounted to only 43 percent of that available at the outset of the research program. Declining financial support caused the Beach Erosion Board to move away from basic research to reimbursable studies for other agencies. While this kept facilities busy, the basic knowledge that advanced theoretical understanding suffered.[37]

Results from BEB research varied. A study of steel sheetpiling in coastal waters yielded reliable data on the expected life of piling exposed to various amounts of saltwater and wave action. Three separate studies provided a means to evaluate the loss of energy of observed or predicted deepwater waves resulting from bottom friction and percolation.[38] A laboratory study of the factors affecting beach profiles revealed what types of waves could be expected to tear down or rebuild a beach.[39] However, the board did little study of the effectiveness of sand fill or sand bypassing to replenish beaches, nor did they test wave forecasting methods thoroughly (though they promised to revolutionize ideas concerning ocean wave generation).[40]

In the 1950s, the BEB was called on to provide information more frequently. The decade's early years saw greater development of the coastal zone as recreation, home building, and small craft boating boomed. Increased coastal occupancy meant old problems had more serious consequences. Six hurricanes hit the Atlantic coast over a 13-month period in 1954 and 1955, taking over 500 lives and causing more than $2 billion in damage. People called for more Federal involvement.

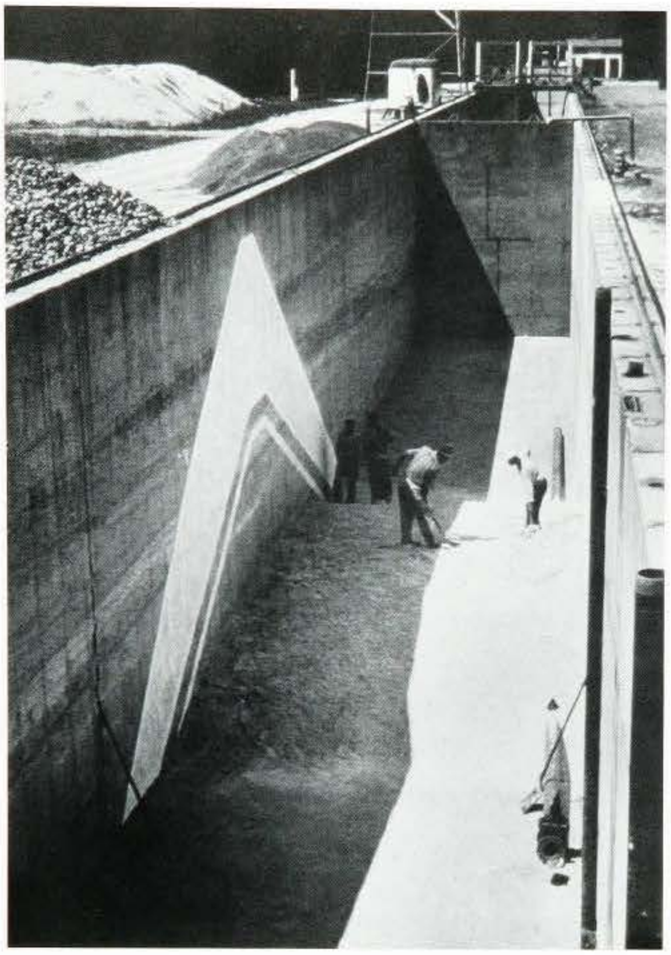
Responding to public fears about future hurricane surges–including warnings that the subways in New York City would flood – Congress authorized the Corps to cooperate with other Federal agencies in examining the eastern and southern seaboard to secure data on hurricane behavior and frequency, determine methods of forecasting and improving warning services, and find the "possible means of preventing loss of human lives and damages to property."[41] Though this legislation did not increase Federal assistance available to states for erosion control projects, it did provide new ways to justify projects economically.

The Beach Erosion Board took the hurricane survey authorization as a mandate to analyze the causes of hurricane damage, calculate the dollar value of projected losses, and develop ways to prevent or minimize the destruction. The board's objective was to submit to Congress practical project proposals. The approach worked. Congress, which up to 1954 had authorized only five shore protection projects, approved 62 in the Rivers and Harbors Acts of 1954 and 1958. Between 1950 and 1960, the board completed 51 cooperative studies and had 31 more in progress at the end of the decade.[42]

By the late 1950s, new coastal zone programs were being established by the Navy, the National Science Foundation, and the Atomic Energy Commission. Studies contracted by the Beach Erosion Board, along with Navy contract work, increased the number of centers engaged in coastal engineering. The University of California at Berkeley, New York University, the Massachusetts Institute of Technology, Scripps Institution of Oceanography and Northwestern University became involved. The expanded interest in coastal studies was not limited to the United States. After major storms in 1952 and 1953 flooded England and the Low Countries, the Dutch set up a laboratory at De Voorst; the French increased their efforts at Grenoble; and the English, Danes, and Norwegians set up research stations. Japan, beset by tsumanis, began work in coastal engineering to protect power stations. The Soviet Union also undertook a major research program after World War II.[43]

Beach Erosion Board and Expanding Programs

As interest in coastal zone phenomena grew, the BEB gained research competency. In the postwar years, the board had acquired such test facilities as a large outdoor prototype wave tank and a shore processes test basin at its site on 15 acres in the Corps-operated Dalecarlia Reservoir in Washington, D.C. The BEB set up field research groups to begin hydrographic surveys, beach research, and other data collection and established lines of communication with the District offices. In time, this led to hydrographic surveying work being assigned at the



Preparing Dalecarlia Large Wave Tank for Testing, Circa 1960

District level. The board also contracted for research to be done by universities and other institutions and by the Corps' Waterways Experiment Station at Vicksburg, Mississippi. In 1955, after funding was delayed during the Korean War, the BEB was able to complete a 635-foot-long wave tank. Holding approximately a million gallons of water when filled to test level, the tank generated 6-foot breakers for the study of beach equilibrium profiles, wave runup (how high waves will run up on structures under different conditions) and overtopping, and the stability of structures designed to withstand the sea's battering.[44]

The Beach Erosion Board, like other government research centers, attempted to hire more qualified personnel. However, the Federal environment in the 1950s was not as conducive to improving professional competency as it would be later. Experts with specialized knowledge were hard to find and retain in light of the bureaucratic hurdles of that time. The early years of Rudolph Savage's tenure – he would close his career as Chief of CERC's Research Division – demonstrate the problems. Savage joined the BEB in 1950, with a background in general engineering from North Carolina State University. To get the necessary specialized training in coastal engineering, he asked for a leave of absence to attend Texas A&M University. (The school had a physical oceanography program financed with money from oil companies working to develop the gulf.) When he was refused, he simply quit the board and went to school. When he completed his studies, the BEB rehired him.[45]

By the mid-1950s, the Beach Erosion Board had evolved into an organization of approximately 42 people operating in relative isolation from other Corps activities. The academic atmosphere tended to draw people who were creative and progressive. Some came from universities because they could find more challenging work in government service. Between 1959 and 1966, the American Society of Civil Engineers made 35 awards for recognition of research related to civil engineering; six went to Federal employees. Of these, three were awarded to CERC staff members, the only representatives from the Department of Defense.[46]

Beach Erosion Board Research Publications

Beach Erosion Board research may be divided into two broad categories. The first involved study of the physical phenomena of the coastal zone: wave behavior, currents, factors influencing the movement of beach materials, and the design and effects of man-made structures. The second was a program of gathering and compiling data on the U.S. coastline. In 1950, the BEB staff began assembling information for a report published in 1953 as Special Issue No. 2 of the *BEB Bulletin*. Recipients were asked to forward critical comments. The original manuscript then was revised and the first edition of *Shore Protection, Planning and Design*, Technical Report (TR) No. 4, was issued the following year. The BEB distributed 550 copies, the U.S. Government Printing Office (GPO) sent several hundred others to Federal repository libraries, and 2,000 copies were placed on sale at the GPO. The first edition sold out by August 1958.[47]

The first major revisions to TR 4 were issued in August 1957. They principally concerned the forecasting of wind-generated waves, generation of

wind-waves in shallow water, wave runup and overtopping, and the modifications in a formula for the stability of rubble-mound structures. In all, the BEB replaced 44 pages with 89 new pages for insertion and included instructions for pen-and-ink changes. Because the inserts created an awkward arrangement, the board printed a second revised edition of TR 4 in 1961. It included new forecasting curves for wave spectra, revised hurricane surge calculation procedures, and added material dealing with wave forces on pilings and rubble-mound stability. This time the BEB distributed 1,200 copies, and the GPO sold an additional 2,500 copies.[48]

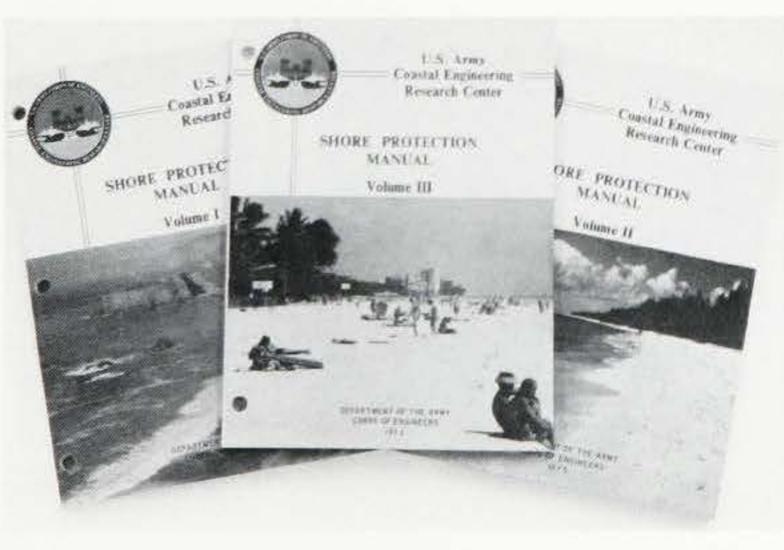
In 1966, a completely new third edition was prepared. Principal revisions included substitution of revised diffraction diagrams, new shallow-water wave-forecasting curves, additional data on sand-size-analysis parameters, and an amended chapter on structural analysis. In addition to about 500 copies to the Coastal Engineering Research Center and the usual GPO distribution to Federal repository libraries, 5,000 copies were sold at GPO. By May 1968, with only 872 copies remaining for sale at GPO and with CERC's supply exhausted, a new printing was ordered. In 1973, having established the framework for research in the coastal zone, Technical Report No. 4 was succeeded by the publication of CERC's *Shore Protection Manual*.[49]

Beach Erosion Board Public Contributions

Largely as a result of its own investigations, the board came to view the construction of protective works such as groin fields, usually the first choice of property owners, as the least successful and economical solution to erosion problems. Hence, though special-interest groups continued to seek Federal financing of seawalls, bulkheads, and groins, the BEB consistently favored restoring beaches through sand replenishment. This process was expensive, however. Moreover, beach nourishment was considered project maintenance and therefore not eligible for Federal funding. Citing the BEB findings, the Corps pressed for legislative language that redefined project construction to include "the deposit of sand fill at suitable intervals of time to furnish sand supply to project shores."[50] In 1956, Congress amended the law and incorporated the Corps-recommended changes.[51]

Trends of the Late 1950s

In 1956, sufficient support for protecting property owners in high hazard zones led Congress to pass a flood insurance act initiating studies leading to a workable insurance plan. When investigations showed that the insurance statute would provide for the uneconomic construction in hazardous areas using Federal money, Congress declined to provide funds to implement the new law.[52] The problem of how to aid seashore residents remained.



Shore Protection Manual, 1973 Edition

Federal agencies also began to reexamine national water policies. A new interest in land use management techniques for flood control, pioneered by the Tennessee Valley Authority, grew in importance. In 1959, the Senate Select Committee on National Water Resources was formed. With the aid of a number of people interested in new legislation, by 1961 the committee had won Congressional endorsement of comprehensive planning and coordination for water resources projects.[53] By 1960, when Congress amended the 1930 erosion control act to permit Federal financing of the Federal-State studies seeking ways to prevent

erosion, a major reorientation of Federal programs affecting water resources was underway.[54]

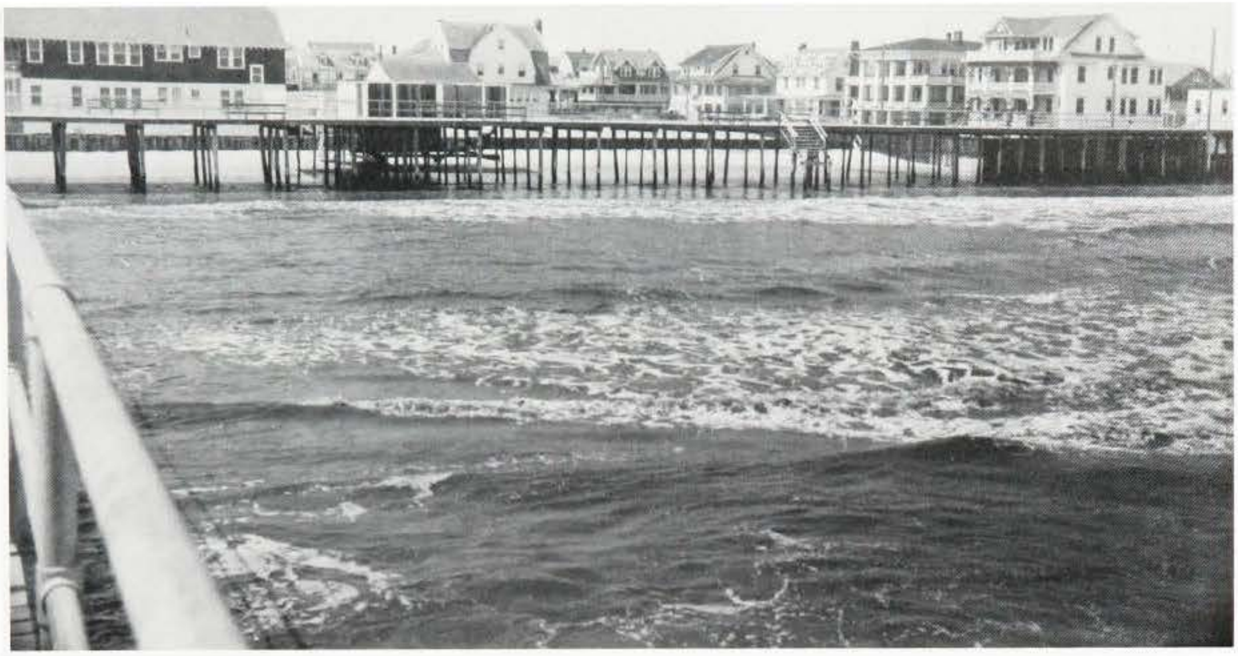
Nature rudely punctuated the legislative evolution in 1962 when the Atlantic storm of March 5-9 rode five astronomical tides to become one of the worst storms ever to strike the eastern seaboard. Damage stretched from New York to Miami Beach. In September came the most destructive hurricane ever to hit the gulf coast.[55] As in the past, the disasters led to public demands for Federal action. Congress responded in October 1962 by authorizing Federal funding to reimburse local interests up to one-half the costs for work on Federally authorized erosion-control projects subsequent to cooperative studies done with the Corps. The law now provided Federal financing for up to 70 percent of the costs (exclusive of land costs) to protect public facilities that excluded permanent human habitation, meaning state parks and the like. In addition, the Secretary of the Army was authorized to undertake construction of small shore and beach restoration and demonstration projects not specifically authorized by Congress up to a total of $3 million in any one fiscal year.[56]

Opposing elements affected both Congress and the Corps as they focused on the coastal zone. On the one hand, criticism of Federal construction practices, growing awareness of the rising cost of flood protection, and the desire to hold down public expenditures created demands for less costly projects and reinforced the Corps' conservativism. On the other hand, several factors pushed the Corps toward more involvement in coastal construction. Twenty-two of the Corps' 38 Districts bordered the coastline and were engaged in analyzing coastal processes affecting planned or completed projects. But the usual work of the Districts was design, construction, operation, and maintenance–not research. While some of the tidewater and coastal data the Districts collected and included in project design reports were published as Congressional documents, Districts had no authority to collect and analyze general coastal data.[57]

Also, the impetus to expand the Corps' research and development programs to keep pace with the rapidly emerging national oceanographic program had become a powerful force. The Corps' involvement in the coastal zone had grown too large and complex to be handled under the organizational structure of the Beach Erosion Board. A new Corps agency promised lower costs and better program coordination by consolidating duplicate review functions.

For all these reasons and more, the Corps perceived benefits from having the evaluation and reporting of coastal projects follow the same procedures as river, harbor, and flood-control studies. Creating CERC was also good politics. In 1962, the Corps studied the merits of strengthening its coastal research capabilities.[58] The next year, Congress, responding to recommendations of the Corps' special internal study board, established the Coastal Engineering Research Center and defined its missions.[59]

The Beach Erosion Board had done much during its 33-year existence. It had reviewed 149 cooperative study reports and two Federal surveys of beach erosion problems. Since the 1946 legislation allowing Federal participation in construction costs, the BEB reviewed 114 reports and recommended 72 as appropriate Federal projects. In the same 33-year period, the BEB had published 135 technical memoranda and four technical reports. Of this total, 130 were issued after the 1945 legislation authorizing the BEB to make general investigations and publish technical reports.[60] The Beach Erosion Board had established a base for the larger, stronger Corps program assigned to CERC.



Before and After Views of Shore Development, Prospect Beach, West Haven, Connecticut, 1956 and 1957

II

COASTAL ENGINEERING RESEARCH CENTER: ORGANIZATION AND MISSION

Coastal Engineering Research Board

To obtain the necessary expertise for its investigations, the Beach Erosion Board had both civilian and military membership. While military officers rotated frequently, the board had only five civilian members in its 33-year existence. Because the Corps felt that continuity was important to the success of the board's research programs, the advisory system was retained when CERC was established. Legislastion provided that CERC's Coastal Engineering Research Board (CERB) would be composed of four senior officers of the Corps, three of whom normally would be Division engineers with coastal engineering responsibilities; three civilians prominent in the field of coastal engineering appointed by the Chief of Engineers; and the Director of Civil Works, who would be president of the board. The CERC director would serve as executive secretary.[1]

The Coastal Engineering Research Board was well positioned in the organizational structure. Line authority for other Corps civil works studies extended from the Chief of Engineers to the Director of Civil Works and then to the Corps agencies, Divisions, and Districts. The CERB and CERC coastal engineering research program operated at the level of the Director of Civil Works. The CERC had legislative charter to consider all Corps coastal engineering research programs and also to serve as an advisory board to the Director of Civil Works or the Chief of Engineers, who would coordinate programs and provide broad policy guidance.[2] At the second CERB meeting, in August 1964, Major General Jackson Graham, board president, stated that CERB would review not only CERC's program but the coastal engineering portions of the programs of the Waterways Experiment Station and the U.S. Great Lakes Survey as well. The CERB would then recommend priorities for accomplishing research projects "in consonance with the needs of the coastal engineering field and the objectives of the Chief of Engineers."[3]

Though only advisory, CERB could exercise a powerful influence over CERC. Some CERC directors would follow CERB's guidance, others would try to anticipate the board's wishes, and still others would try to use CERB to advance CERC interests. However none would ignore it. The CERB would obtain significant budget increases in the mid-1970s, for example, by convincing OCE that CERC needed the funding.[4]

Before CERC's creation, coastal research in the Corps was funded from two accounts. The first and largest consisted of the BEB General Investigations funds administered by the board's staff. This money represented approximately 80 percent of BEB yearly funding. The second source was the OCE Civil Works Investigations (CWI) budget. Congress allocated CWI funds to OCE for various civil works activities, including research for coastal projects. The Engineering Division in the Civil Works Directorate of the Office of the Chief of Engineers administered these funds. Prior to any suballocations for research, Corps field offices and laboratories were invited to submit proposals for projects to be supported. The OCE staff then disbursed funds. While some OCE-approved projects were in the field of coastal engineering, most were in other areas. From a CWI funding total of $1.3 million in Fiscal Year 1963, for example, $209,000 was allocated to coastal engineering. Of this, $84,000 went to the Beach Erosion Board. Of the funds annually allocated to the BEB, only about 20 percent were subject to prior approval from the Civil Works Directorate.[5]

The CERC was funded in a slightly different manner. Money for its program was shown as a separate line item titled "Coastal Engineering Research" in the General Investigations budget.

Coastal engineering research projects continued to be included in the CWI budget. To ensure appropriate control and coordination, the Director of Civil Works administered CERC research funds in the same way as he had CWI funds. The CERC submitted quarterly progress reports to the Director of Civil Works describing the progress of research and the status of expenditures. To some, changes in the funding procedures suggested CERC might not enjoy the organizational autonomy of the Beach Erosion Board.[6]

The CERC's initial decision to pursue field measurements and basic oceanographic laboratory studies had wide support. By the mid-1960s, Corps leaders anticipated that budgets for the construction, operation, and maintenance of all coastal projects would rise to about $175 million by the end of the decade. Approximately $90 million was earmarked for project work along the coasts, the other $85 million for maintaining navigation channels in tidal waterways. Assuming the Center's research paid off at a rate of 10 percent of these costs in direct dollars or improved facilities, the Corps could anticipate saving as much as $9 million in coastal areas and $17.5 million overall. The theory was that more research would produce more data and lead to greater savings.[7] Those reviewing CERC programs were inclined to agree with the conclusion of CERC Director Colonel F.O. Diercks that while "the actual evaluation in dollars of the benefits of the research program in coastal engineering appears impracticable," the basic research was important.[8]

Within the Corps, the initial division of research responsibilities gave CERC the primary responsibility and the Waterways Experiment Station a supporting role in all basic coastal zone studies.[9] The CERC and WES cooperated to divide the work: CERC would do studies with general application, and WES would carry outcoastal model studies of specific locations. Guidance from OCE that held out a promise of increased research and development funding for coastal research eased problems associated with working out the arrangement.[10] In 1969, Colonel Edward M. Willis, Director of the Corps' Research and Investigation Programs, recommended that CERC be given primary responsibility for research on the effects of coastal engineering activities on the coastal ecology.[11]

Many Corps leaders hoped that CERC would prepare the Corps to explore opportunities in the coastal zone. "Historically, we in the Corps have been generally project oriented," wrote Brigadier General John A. B. Dillard, South Pacific Division Engineer, to Brigadier General Harry G. Woodbury, Jr., Director of Civil Works, in 1967. He added, "We have had little interest in investigations leading to new concepts." With both public interest and Federal involvement in coastal zone increasing, Dillard suggested, Corps policy might be unclear. "[I]n light of our long time involvement in estuaries, shoreline and navigation matters along the coast, it would be more difficult to eliminate the Corps from the field if we 'seized the mission' by formal declaration, special staffing, and the assignment of area responsibilities to include the continental shelf. I recognize," he continued, "that this represents, in essence, a research type function, for which we have no funds, specific authorization, or specialized staff at the field level." Dillard concluded that the Corps should explore the possibilities. Woodbury seemed to agree, noting the Corps' increased involvement in the coastal zone. He cited the increase in the CERC budget from $850,000 in FY 1965 to $2.5 million in FY 1968. "The prospects for further increases are good," he added.[12]

Spurred by both burgeoning increasing coastal development and environmental awareness, CERC personnel planned programs to quantify phenomena that they understood only qualitatively. The new work would require increased funding, but larger CERC budgets could be justified. The Marine Resources and Engineering Development Act of 1966 declared a long-range policy of accelerated Federal research of the coastal zone. Both the Panel on Oceanography of the President's Science Advisory Committee and the National Council on Marine Resources and Engineering Development, established under the 1966 act, advocated additional effort. In transmitting to Congress the Second Annual Report on Marine Resources and Engineering Development, President Lyndon Johnson in 1968 proposed increased funding, especially for broadening education and speeding up research in marine sciences.[13]

The Marine Science Council made the Corps the coordinating agency in an interagency, multidisciplinary effort to determine the effects of engineering construction on the ecology of the coastal zone. The same year, an OCE command inspection team recommended that CERC draft a program covering the Corps' long-range needs in coastal engineering. This triggered a reevaluation of CERC's and the Corps' roles and needs in coastal research and sug-

gested a possible increase in the contemplated long range, $5 million program.[14]

Early Plans and Programs

The tentative five-year program for Fiscal Years 1964-1968 called for coastal research budgets that would increase from $814,000 to $1,238,000.[15] Projected ten-year research expenditures, which included the OCE program, contemplated budgets totaling $9,250,000 to $16,675,000 over the next decade. The long-range organization plan for CERC between 1966 and 1975 was even more ambitious. This plan, essentially the ten-year Corps program in oceanography that had been approved by the Federal Council on Science and Technology and built into CERC's expanded missions, proposed funding increases from $1,100,000 in FY 1966 to a maximum of $5 million in FY 1971 and a like amount thereafter. The plan authorized increasing CERC's staff from 75 to 131 people by FY 1970, suggested ways to meet CERC's major physical property requirements in the near future, and anticipated additional equipment purchases.[16]

The CERC planning was consistent with Corps expectations. The Center had requested 30 additional staff positions in 1965, received 14, and was advised by OCE to ask for the remaining 16 in the FY 1967 budget.[17] Planners at OCE and CERC assumed that future funding for coastal-zone research would increase, even though the Corps had few construction projects along the coast and, proportionally, basic research was a greater component of CERC's program. However, none of this appeared to pose a problem because CERC's operations were financially sound. In the early 1960s, plans, income, and expenditures were in reasonable balance. In FY 1964, in fact, the research program had more funds available than were budgeted,[18] and the balance of in-house and outside research was about equal.[19]

The CERC received the support it expected. Budgets increased between 1964 and 1969, and by 1968 CERC research studies were being funded at 1.5 percent of the Corps' total coastal program, significantly more than research expenditures in other areas.[20] No one – at CERC, in OCE, or elsewhere in the Federal establishment — suggested that CERC managers should rein in their plans, resist expansion, and stabilize funding levels. Thus, in 1970, the CERC staff five-year plan proposed an increase in the research and development program from $3,250,000 in FY 1971 to $10 million in FY 1975.[21] In 1969, CERC had a complement of 1 officer and 91 civilian personnel; long-range plans called for 225 people by 1980. Reorganized and expanded, CERC looked forward to being increasingly influential.[22]

Earlier Corps success in coastal zone construction, some dating back to the turn of the century, lent considerable credibility to the Corps' commitment to CERC. The economic benefits resulting from completed Corps harbor construction projects were obvious. The Los Angeles Harbor Outer Breakwater had allowed the development of one of the great harbors of the country. The Delaware River ship channel facilitated the development of a large industrial complex and port facilities along that river. The Harrison County, Mississippi, project provided both shore protection and major recreational benefits. Since 1952, the Corps had maintained a beach erosion control project at Virginia Beach, Virginia, that had prevented or reduced damage to that highly developed area, particularly during the March 1962 storm. None of the glaring failures in coastal zone construction could be attributed to the U. S. Army Corps of Engineers.[23]

Recent successes from Beach Erosion Board research augured well for the future. Building or stabilizing sand dunes with fences and vegetation already had proved less expensive than adding sand. Experimental studies carried out on the Outer Banks of North Carolina showed the relative effectiveness of straight fences in building dunes. Research on storm surge and wave runup relating to the Texas City hurricane levees prompted the elimination of $3 to $4 million of riprap initially designed for levee protection. Wind and wind-tide studies in shallow waters resulted in savings in the construction of new dams and levees for Lakes Okeechobee and Pontchartrain. Improved dredging methods significantly reduced cost for dredging the Delaware River channel. Engineers could cite numerous instances where better coastal engineering research would have enabled the Corps to avoid later problems. Had research on wave transmission through permeable breakwaters been completed prior to construction of the Redondo Harbor, Marina Del Rey, Los Angeles, and other California projects, CERC reported, the Corps would have realized substantial savings.[24]

Coastal Zone Studies

Though the largest of the U.S. water resources development agencies, the Corps of Engineers spent

only 5.3 percent of the total U.S. investment in water resources research. Most Corps research funding was actually project money, and only the largest projects had sufficient funds for proper research, whether it dealt with inland hydraulics, structures, soil mechanics, or cold regions.[25] Many in the Corps, and especially in the CERC staff, considered CERC's research mission special.

In the 1950s, the Beach Erosion Board had initiated a program to divide the United States into regions with similar coastal conditions. The staff began to assemble a data bank on wave climatology, offshore changes, sand characteristics, and discharge from rivers so information would be available to the Districts. That the District engineers did not know how to use the data to get answers soon became apparent. When CERC was established, the program was broadened to include general studies to advance the field and enable Corps Divisions and Districts to solve specific problems. Because Congress already had directed CERC to provide information concerning shoreline protection deemed "to be of value to the people of the United States," the decision to point CERC toward basic research required no further review.[26]

Moreover, making CERC a center for research suited the staff. The CERC's special status was underscored in 1974, after the Engineering Regulation establishing CERC was revised and the mission of basic research reaffirmed: CERC, wrote one high ranking staffer, was now the Corps' "Office of Naval Research."[27]

Although CERC had been given the primary mission for Corps coastal zone research, it was not alone in the field. The Waterways Experiment Station, the Great Lakes Survey, and the Committee on Tidal Hydraulics had coastal engineering missions.

In 1948, the Chief of Engineers established the Committee on Tidal Hydraulics to evaluate and publicize the current knowledge of tidal hydraulics and related phenomena. The Chief also charged the U.S. Great Lakes Survey with a coastal engineering research program that included measuring harbor currents and lake waves in three of the Great Lakes, investigating water-level disturbances, and studying energy transfer at the air-water interface, shore processes, coastal area sedimentation, and sediment barrier effects.[28]

When CERC was created, each of these organizational subunits of the Corps had well-established programs. The Committee on Tidal Hydraulics was revising a chapter in the Engineer Manual *Tidal Hydraulics*. The WES had acquired wave generators and surplus aircraft hangars to shelter physical models after World War II, constructed additional facilities, and created an extensive research program in its Estuaries Branch. By 1964, one WES study sought to develop the analytical model for predicting effects of saltwater intrusion in open channels. Another study sought ways to predict flow patterns and current velocity distribution in tidal entrances. An ambitious undertaking attempted to identify the natural factors involved in shoaling processes. A low-priority project involved cataloging and summarizing pertinent WES data on the physical, hydraulic, and shoaling characteristics of specific estuaries. (Providing engineers with a quick reference for specific estuaries would assist them in comparing estuaries and identifying suitable improvement works.)[29]

Storm Damage at Ocean City, Maryland, 1962

Other studies concentrated on improving the design of rubble-mound breakwaters by testing three-dimensional laboratory models under varying wave attacks. In these, wave generators simulated natural conditions.[30] By 1964, the WES Research Library was preparing a fourth supplement to the bibliography on tidal hydraulics, scheduled to be published in 1966. To help keep pace with rapidly expanding knowledge, the Committee on Tidal Hydraulics and WES in 1964 were ready to develop an internal document that would differentiate between the known areas of tidal research.[31]

The Coastal Engineering Research Center and the Waterways Experiment Station had similar, complementary test facilities. The CERC had the 300-foot-long by 150-foot-wide basin used to develop information on the distribution and quantity of littoral drift. The Tidal Inlets Committee at WES was in the process of acquiring three test basins. Facility A was a 150-foot-long by 50-foot-wide basin that simulated inlets of various characteristics under varying tidal conditions. Facility B was another 150-foot-long by 50-foot-wide basin. It consisted of an "ocean" in which tides of various amplitudes and periods could be generated, a "lagoon" that could be varied in area, shape, and depth, and a connecting section. Facility B allowed detailed modeling of inlets of various characteristics. Facility C, a 350-foot-long by 150-foot-wide basin, was used primarily to study the dynamics of various inlets under the combined influence of tides, waves, littoral drift, and other significant factors. It had a movable-bed "ocean" equipped with appurtenances for generating tides, waves, littoral currents, and other forces; a fixed-bed "lagoon" that could be varied in area, shape, and depth; and a connecting movable-bed barrier beach and inlet section for modeling various characteristics by movable-bed model techniques. In addition, the WES Estuaries Branch had no less than seven coastal engineering models where tests were ongoing.[32]

The CERC and WES investigations overlapped, particularly in the Corps' General Investigation Tidal Inlet (GITI) Studies research program. Understanding that the work was to be basic research, CERC allocated $165,000 in FY 1965 and 1966 to WES so that the Hydraulics Division could proceed with the construction of Facilities A, B, and C.[33] When the Hydraulics Division altered the inlet models to test specific designs, a sharp difference of opinion developed. In April 1967, the civilian members of CERB visited WES as a subcommittee to look into the matter. Their report backed CERC's contention that the basins were being used for specific model tests instead of basic research.[34]

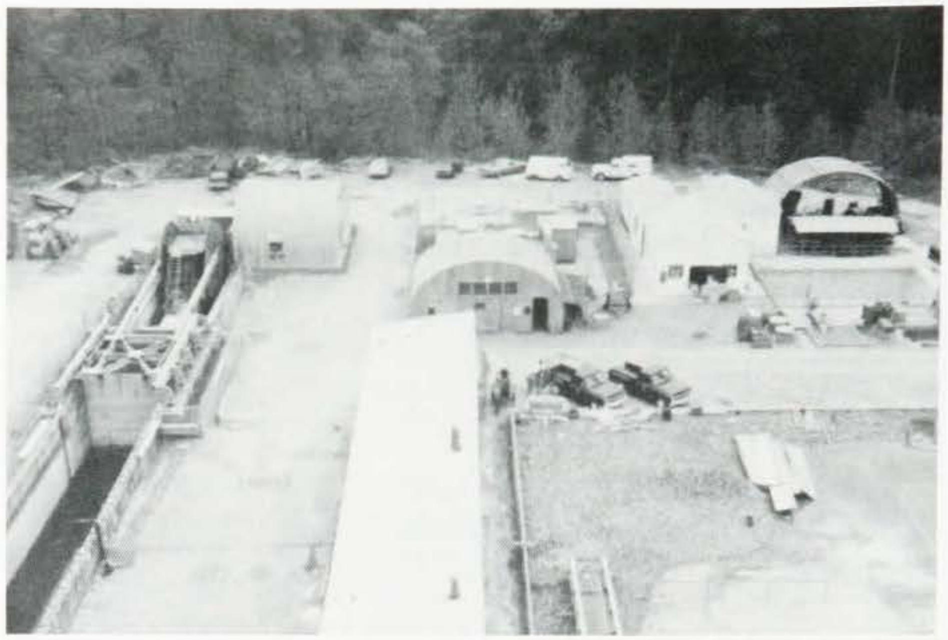
At a subsequent executive session, CERB recommended that CERC be given overall control of the inlet studies at WES using Facilities A, B, and C. General Woodbury agreed to have OCE look into the matter.[35] Soon, OCE made a decision designed to appease both CERC and WES: The GITI Studies would be funded as a research project. The study facilities at the Wave Dynamics Division (WDD) would not be used for project model studies, but WES would continue to control their use.[36] The decision in effect limited the WDD of the WES Hydraulics Laboratory to basic research. The Division soon dwindled to approximately six people who mainly carried on breakwater modeling tests. The CERC viewed the arrangement as permanent. However, the guidance from OCE in no way precluded the WDD from conducting basic research in tidal inlet phenomena by using other techniques.[37]

Relocation and New Facilities

As CERC assumed new missions, Corps plans to acquire better facilities set off a series of events that concluded with CERC's relocation to Fort Belvoir, Virginia. In 1957, the District of Columbia Committee of the Senate had urged the Department of the Army to transfer the Dalecarlia reservation, which was occupied by the Beach Erosion Board and the Army Map Service, to the Washington Aqueduct authority. But the Corps opposed moving the Beach Erosion Board to Fort Belvoir because the estimated costs exceeded $1 million.[38] In fact, having outgrown its facilities, the Corps was planning to erect a new building for the Board of Engineers for Rivers and Harbors at a site in the Dalecarlia Reservoir area and to add new equipment. The most important of the equipment needs were replacements for the shore processes test basin (SPTB) portable wave generators, which had cost $10,000 each in 1951; a 96-foot wave tank generator, completed in 1958 at a cost of $3,200; a 72-foot wave tank generator, which could produce irregular waves, completed in 1966 at a cost of $29,100; and a tank for large waves, completed in 1955 at a cost of $250,000.

The CERC's most critical needs were office space and a shelter for the SPTB. Exposed to all weather conditions, the SPTB could be used effectively only from April through October. Proposed

increases in CERC's research program from $200,000 in 1962 to approximately $1 million in 1965 indicated that year-round operation of the SPTB would be necessary. In 1964, CERC asked for approximately $500,000 to construct a shelter.[39]



Expansion of Facilities at Dalecarlia, Circa 1960

Meanwhile, in February 1963, OCE had forwarded to the National Capital Planning Commission and other interested agencies a master plan calling for the transfer of parcels of land from the Washington Aqueduct to the Army Map Service. In July, the commission voted against the transfer and recommended that the Army Map Service move. The lines of disagreement were drawn more clearly at a conference in September when the Planning Commission asked the Corps to indicate its comprehensive plan for future land use of the Dalecarlia site, particularly as related to the Army Map Service and the Board of Engineers for Rivers and Harbors (BERH).[40]

In December, the Baltimore District Engineer submitted a general site plan of the Dalecarlia complex to a coordinating committee of the Planning Commission. The commission promptly tabled the site plan of the BERH complex pending receipt of recommendations from the District of Columbia Director of Public Health. He soon advised against siting the BERH building in the Dalecarlia Reservoir watershed. By January 1964, the National Capital Planning Commission had rejected substantial portions of the Corps' plans, including the new building to house the Board of Engineers for Rivers and Harbors.[41]

Faced with a determined Planning Commission, the Corps sought other options. One was to transfer CERC to Vicksburg, in effect making the Center a WES laboratory. The CERC personnel and others had some compelling objections; CERC was situated in Washington, where staff had direct contact with other agencies and work groups in the mainstream of oceanographic research and where CERC's trained engineering staff was available to OCE, the Board of Engineers for Rivers and Harbors, and other Government agencies needing advice and assistance, they argued. (Privately, CERC staff admitted that proximity to OCE also meant CERC budgets could be promoted at the executive office level.)

Opportunities for advanced education in the Washington area far exceeded those that would be available at Vicksburg, CERC staff said. They noted that between 1963 and 1965, five of the seven members of the professional research staff of CERC's Research Division had done advanced study in the metropolitan area. Involved in extensive travel relative to the size of the staff, CERC personnel benefited from the excellent air service from Washington. In contrast, the closest and rather inadequate airport to Vicksburg was in Jackson, Mississippi. All of these factors indicated that a move to Vicksburg probably would cause a significant loss of staff. Also cited was the relatively inferior educational system for children through high school. But most important, at Vicksburg, CERC's status would change. As CERC commander, Colonel Diercks, stated:

> The principal motivation of the entire CERC staff, from Director down, is Coastal Engineering research. The next point of reference at present is the Director of Civil Works, OCE. At Vicksburg it would be difficult to keep CERC from being involved in or becoming a part of the much larger administrative and executive complex of WES. It would seem that CERC actions

would inevitably become somewhat submerged at WES to the more pressing demands of engineering model work for specific engineering problems.[42]

In the end, OCE found CERC's arguments persuasive.

Behind the scenes at CERC, more serious planning studies weighed the advantages and disadvantages of a move to Fort Belvoir. While Dalecarlia offered CERC a location satisfactory for its present size, office space was barely adequate, and laboratory expansion into outdoor covered tanks was severely limited. Also construction and maintenance costs were lower at Dalecarlia than they would be at a new location. Midlevel professional staff and lower grade professionals and nonprofessional staff probably would not make the move to Fort Belvoir. Fort Belvoir was more remote, making employee and visitor commuting more difficult. If the aqueduct were turned over to the District of Columbia government, however, CERC's position would be tenuous.

To determine the advisability of moving to Fort Belvoir, acting CERC Director Joseph Caldwell employed three scenarios. If CERC were expected to grow slowly, it should remain at Dalecarlia. If CERC were to become a much larger operation in the near term, it should move to Fort Belvoir or an equivalent site as soon as possible. If CERC were to see limited expansion over the next four or five years, the Fort Belvoir site should be reserved and CERC should remain at Dalecarlia until adequate funds for the organization's move and expansion were assured.[43]

Though decisionmakers were uncertain about the final shape of the organization, OCE had plans to expand CERC operations quickly. An OCE command inspection of CERC in December 1967 concluded that Dalecarlia had insufficient space for the CERC of the future. In early 1968, OCE developed a plan to construct a research and development complex on 450 acres in the northwest corner of Fort Belvoir, about 18 miles southwest of Washington.[44]

The design envisioned locating several Corps and Department of the Army agencies within the Fort Belvoir complex. The Kingman Building, costing \$3.626 million, would house CERC, the Board of Engineers for Rivers and Harbors, and the Institute for Water Resources. A 100-acre section would be allocated to CERC for the replacement of existing test facilities and for future expansion requirements. Space would be reserved in the Kingman Building for a CERC staff of 130 as well as data processing, a library, test facilities, and other CERC requirements. The Kingman Building's configuration would take into account CERC's projected expansion as set forth in the long-range master plan for coastal engineering research, then being developed. The CERC's existing test facilities, the large wave tank and shore processes test basin, would be reproduced at the new site, and the SPTB would be covered. Later construction at the new site would include a second large wave tank, a circular tank, and a tsunami basin. Final Corps plans thus endorsed both the rapid expansion of the CERC and its relocation to Fort Belvoir. Congressional approval to carry out the program came in 1968.[45]

In retrospect, though major facilities were constructed at Fort Belvoir, more should have been done to upgrade equipment. The large wave tank needed to be made at least 750 feet long. It also required an overhead traveling crane at the generator end and needed upgraded electrical and other control systems. The shore processes test basin needed better

Kingman Building, Fort Belvoir, Virginia

lighting than the design provided, additional drains, outlets, and other equipment, and, above all, new generators. The 72- and 96-foot flumes should have been discarded and replaced with two new 150-foot wave tanks with modern equipment. A multispectral generator costing an estimated $1.6 million was not purchased, and the large wave tank thus continued to use an old monochromatic wave generating mechanism. (Eventually, the drive converter was upgraded at a cost of approximately $80,000.) These and many other equipment needs were not met because OCE planners arranged the move with the understanding that the Corps would recreate CERC facilities, not underwrite major improvements. Facilities upgrading was limited to the smaller wave tanks, which were lengthened during the relocation (one was given a spectral generator).[46] Put bluntly, Corps planning left much to be desired. After deciding that CERC was to be a state-of-the-art research center, the Corps focused on the short-run costs of relocation and essentially moved aging equipment into new buildings.

The CERC's move to Fort Belvoir turned into a contracting nightmare. Costs ran over budget, the CERC organization was reshuffled, and it took almost two years to get back on track. Ten obsolete generators for the shore processes test basin were to be replaced. However, numerous problems delayed the acceptance test of the prototype spectral generator when the new SPTB was completed in 1976. This in turn delayed procurement of six other generators CERC needed. Then plans were changed; procurement of the spectral generators would be staggered. The CERC soon faced problems in funding equipment purchases.[47]

The CERC facilities at Fort Belvoir were dedicated on 21 August 1975, two years after the move from Dalecarlia, as the Jay V. Hall Laboratory. In the principal address, Chief of Engineers Lieutenant General William C. Gribble, Jr., reaffirmed the Corps' commitment to coastal zone engineering. The laboratory was an investment in the future of the Nation's coastal resources, he said, and he termed the ceremony a dedication to new knowledge.[48]

The CERC would be hard pressed to live up to these standards. The move to Fort Belvoir brought the Center new fiscal obligations. Construction was financed through the Corps' revolving fund, a line item in OCE budget that enabled Districts, Divisions, and other Corps elements to "borrow" money for capital expenditures rather than try to get a line item

Jay V. Hall

in the Congressional budget. What is borrowed must be paid back, however. Rudolph Savage, who retired as Chief of the Research Division, later would observe that using the revolving fund to pay for the Fort Belvoir facility turned out to be the equivalent of living in a house with a 4-percent mortgage, then being forced to move to one with a 16-percent mortgage that could not be paid.[49]

Field Facility

The move to Fort Belvoir also delayed plans to acquire a field research station. The idea had originated after Louisiana State University began field studies in the 1960s and CERC engaged in a research program off Ginnettes Pier, at Nags Head, North Carolina. After observing the work, Rudolph Savage concluded that the simulated environment of wave tanks was indispensable but not sufficient for research. He suggested that CERC acquire a field station. The item was put in the budget and, with the assent of the Office of Chief of Engineers, CERC started building up an acquisition fund. While a laudable idea, in terms of bureaucratic politics it was a terrible mistake. After CERC saved $1.5 million, Congress applied the money to the next year's operating budget. In time, CERC got construction money for the field facility from the Corps' revolving fund.

This added to the total indebtedness and yearly payback load.[50]

The first plan was to locate the field facility at Assateague Island National Seashore. Savage contacted the Park Service, arrangements were made, money was added to the budget, construction plans were drawn, and bids were let. However, only one bid came back, and it was for more than the available money. Before CERC could re-advertise, the Committee to Save Assateague, an environmental group, began raising objections. Related editorials in the *Washington Post* and *Washington Star* suggested that the Corps locate the field facility elsewhere. The CERC completed the move to Fort Belvoir, and plans to add a field facility were shelved temporarily. Then, while on vacation in North Carolina, Savage found another site. In 1971, erosion of the shoreline on Currituck Banks had forced the landward relocation of the Dare County highway. The Navy was preparing to dispose of an abandoned U.S. Navy bombing range at Duck, North Carolina. Savage telephoned CERC Director Colonel Donald S. McCoy, who acted quickly. In 1973, the Savannah District, with its real estate office, obtained the land for the field facility. The Wilmington District supervised construction. The Duck Field Research Facility officially opened on 29 August 1980, the 50th anniversary of the founding of the Beach Erosion Board.[51]

The 182-acre permanent field facility for physical and biological studies of the site, the sound behind it, and nearby barrier islands, bays, and offshore ocean areas included a pier and laboratory built at a cost of approximately $6 million. The CERC soon established an environmental measurements program at Duck to measure and record data on the meteorological and oceanographic conditions at the site. Because the pier offered the opportunity to study coastal phenomena during both normal and past storm conditions, CERC encouraged use of the facility by outside investigators.[52]

Personnel

Obtaining enough qualified people was always a problem. At its first meeting, in April 1964, the CERB discussed the appropriate balance of professional and subprofessional staff members at CERC.[53] At CERB's second meeting, in August 1964, Board Chairman Brigadier General Arthur H. Frye, Jr., said that CERC was poorly organized and needed strengthening, scientists lacked supporting personnel, not enough data were being produced, and the absence of a reports section meant publications were not getting out. The CERB recommended hiring more technicians to support the professionals, particularly in the Engineering Development Division (EDD), and setting up a publications or reports section.[54]

The CERC's budgeting and personnel problems became more complicated after the Duck facility was acquired. Budgeting for a research facility means spending money, using manpower, and allocating time. Data must be collected and quickly analyzed to allow for quality checks and researcher identification. Professional and technical personnel to perform this and other duties were always in short supply. The problem was particularly acute in CERC's Research Division. In 1964, it had 14 aides or technicians, five of whom were student trainees, for nine professional staff. The optimum suggested for university research called for five technicians for every engineer. The CERC ratio of technicians to professional staff was 1.5:1 during the summer months when the shore processes test basin was operated and 1:1 the rest of the year, both well below the suggested 2:1 ratio.

CERC Duck Research Facility Showing Pier During Storm

Recruitment of technicians by CERC was hindered not only by the lack of money and personnel spaces, though these were recurring problems, but also by the inability to select permanent employees from the inadequately updated Civil Service Register and the complicated personnel practices mandated for Government agencies. Obtaining enough professionals so that chief researchers could use their time most efficiently also required explaining to bureaucrats why research differed from other kinds of administrative activity. At the professional level, CERC had difficulty finding such combinations of professional skills as an applied mathematician who understood engineering as well as mathematical problems and who could put solutions into engineering language.[55]

Growth into new areas was another problem. In 1967, Brigadier General Woodbury observed that in an era of increasing environmental sensitivity, CERC had no biologists on its staff. He suggested the Center needed trained specialists in disciplines other than engineering.[56] The next year CERC reported that it had recruited a marine biologist who later rejected the job offer.[57]

Despite personnel problems, reorganization, and the difficult move to Fort Belvoir, CERC's early years were a period of growth and prosperity. Technical Director Joseph Caldwell deserved much of the credit. For reasons not explained in CERC and Corps records, the CERC military commanders were almost always on their last military assignments. A strong, savvy, politically oriented technical director was a great asset. In fact, for several years before the move to Fort Belvoir, when no military commander was assigned to CERC, Caldwell made the decisions.[58]

Joseph Morton Caldwell was born in Yazoo City, Mississippi, in 1911. He graduated from Mississippi State University and then joined the Corps at the Waterways Experiment Station in 1933. He rose to be in charge of all hydraulic model testing; went on active military service in 1942, serving on the staff of the Chief of Engineers during the war; and in 1946 joined the Beach Erosion Board's Research Division. Caldwell served as Chief of the Research Division from 1951 to 1963 and as Technical Director of CERC for seven years. After Hurricanes Carol and Hazel struck in 1954, Caldwell recognized that the Corps soon would be involved in major hurricane protection work. Because realistic design methods would be required for predicting hurricane surge, he initiated the research program to provide this information. After the disastrous East Coast storm of 1962, he developed the "Caldwell section," which was charged with placing the emergency protection fill–some 13 million cubic yards–along the eastern seaboard following the storm. In 1971, Caldwell left CERC to become Chief of the Engineering Division, Civil Works, in the Office of Chief of Engineers.[59]

Joseph M. Caldwell Showing Results of Wave Test to Sir Claude C. Inglis and Col. John Allen

While Technical Director of CERC, Caldwell had an excellent relationship with all elements of the Corps. Well-known and respected as an engineer, with close ties to the Waterways Experiment Station and OCE, he was able to translate basic research into useful Corps technology. Moreover, his adept handling of organizational politics fostered CERC's and the Corps' best interests. As Caldwell acquired both new programs for CERC and the people to do the work, the staff was free to concentrate on basic research in a university-like environment quite different from other Corps offices.[60]

The research orientation continued under Caldwell's successor, Thorndike Saville, Jr., who

Thorndike Saville, Jr.

served as CERC Technical Director from 1973 to 1981. Graduated from Harvard in 1947 with an A.B. in engineering sciences and applied physics, Saville intended to be an engineer dealing with water. (This was natural, given his family background. Thorndike Saville was an authority on coastal zone research and a member of the Beach Erosion Board.) Young Thorndike then went on to the University of California at Berkeley where he received an M.A. in civil and hydrological engineering in 1949. While there, he worked on a Navy project that led to his thesis on sediment transport along the shore. The Corps, interested in the project, offered him a position based on the merits of his work.

Saville went to work for the Beach Erosion Board in 1949. He spent the first year on the west coast doing wave hindcasting for the South Pacific Division. (Forecasting takes today's weather data and predicts wave action. Hindcasting is the technique of "forecasting" the past. An observer takes weather data such as the known pressure patterns taken from ship observations and estimates from the data what wave would have resulted. The prediction is then compared with observed wave conditions.) By using methods developed during World War II, Saville refined and improved procedures to produce mathematical formulations and models. He published a paper and worked to improve his model to forecast wave phenomena. He did pioneering work on wave runup using small-scale tests in BEB laboratories and at WES and developed curves from which one could predict field conditions from model testing. He explored how well the WES facilities modeled by testing waves ten times larger in CERC's large tank.

Unfortunately, CERC's large wave tank could generate waves with only a single physical action, unlike the complex interaction of forces that produce natural waves, and the CERC waves were monochromatic rather than spectral. Nevertheless, Saville derived a method for translating the monochromatic results to a spectrum, as in nature. This type of pioneering work kept the Beach Erosion Board on the research frontier. (Saville's data still form the basis for construction techniques.) Quiet and courtly, he labored diligently as CERC Technical Director to maintain the commitment to basic research with applications to the Corps.[61]

Summary

When formed, CERC was the only Federal agency with a coastal engineering research mission and nearly alone in funding studies of waves and their effects. Personnel knew how difficult, if not impossible, it would be to relate benefits accruing from CERC basic research programs to exact dollar values. But as Acting Technical Director Joseph Caldwell wrote to the Chief of Engineers in July 1967, one could infer that CERC's research had great value. Using a CERC-generated concept that research probably paid off at a rate of 10 percent of the costs in the overall Corps budget, Caldwell calculated that savings of as much as $22,500,000 a year might be anticipated, with up to $11,500,000 realized from research in coastal areas. Sizable benefits also would accrue to local projects and operations, probably far in excess of the Federal savings. For example, the research on waves, wave prediction, and wave forces would provide savings in the expenditures for oil exploration and drilling on the continental shelf and such areas as the North Sea and Persian Gulf.[62]

Critical to CERC's future was the accuracy of these assumptions that undergirded the Center's work.

- The CERC would continue to be the leader in coastal engineering research.

• The CERC would do the important basic research so Corps agencies and the public could benefit.

• The CERC would always have modern facilities and would maintain a staff of researchers who worked at the forefront of the coastal research field.

• The CERB would be the primary advisor to the Chief of Engineers in matters concerning coastal zone research and the advice would be heeded by the Director of Civil Works.

• The CERC Technical Director would always get a hearing at OCE.

• The CERC itself would continue to have the separate line item or its equivalent in the Corps budget.

• The CERC would retain the ability to advocate programs and remain part of the Corps' decision-making process.

• Because coastal research was an area of expanding public and Federal interest, CERC budgets would be supported at the upper levels in the Corps and by the Bureau of the Budget.

On the accuracy of these assumptions, the future of CERC rested.

III

CERC'S BROAD RESEARCH MISSION

Waves, currents, tides, and winds change the morphology of the coast through complex natural processes. Engineers must understand the interaction among the various forces. The critical design requirement for an exposed coastal structure usually is the ability to withstand the largest breaking wave to which the structure might be exposed. Among the factors that determine the maximum breaker height are the depth of the water in which the structure is sited, the beach slope and bathymetry (depth of the sea) in front of the structure, the effects of refraction, the variables that describe the incident waves in deep water, the wave period (the wave's complete cycle), and the postconstruction beach slope. To design properly, engineers need quantitative descriptions of wave characteristics and basic information about wave generation, wave mechanics, and sediment movement. The research programs of the Coastal Engineering Research Center were to provide these data.[1]

Waves and Wave Energy

Among the most important of the natural phenomena of the coastal zone is the distribution of wave energy. It governs the onshore-offshore and longshore sediment transport that reconfigures the shoreline. Most of the energy expended by moving water in the oceans and lakes of the earth originates from extraterrestrial sources such as solar and lunar gravitation, which produces tides, and solar radiation, which unevenly heats the water, creating currents of different densities. Shoreline changes result from the atmospheric pressure differences and winds which act directly on oceans and lakes to produce currents, waves, and storm surges.[2]

Waves occur in the deep ocean both on and below the surface. The formation, propagation, and breakdown of surface waves were studied intensely during and after World War II. As a result, the ability to predict the wave field of the ocean improved enormously, but research in the field still was empirical.

The mechanics of wave generation; the sources of wave energy, frequency, and amplitude; and the directional characteristics of waves remained obscure. Because waves could not be described adequately in mathematical form, the description of their geometry and kinematics relied on observed data. Simply put, when the Coastal Engineering Research Center was established, theory had not yet replaced observation and data recording. Under the circumstances, given the multiplicity of factors involved, solving a design problem by wave analysis meant obtaining the data for a location and presenting them in the most useful form. This was often a costly process. The required empirical investigations from which to derive theory promised to be much more expensive. In the early 1970s, researchers estimated that just to obtain better defined meteorological data for checking wave forecast methods would cost several million dollars over five years.[3]

By 1963, engineers understood that wind-waves and tides were the most significant forces acting on the shore. These forces not only transported sediment, but also complicated the interaction between tidal currents and littoral sand transport at inlets. Engineers needed more information about the effect on sand transport, about the quantitative relationships between the onshore-offshore and longshore sand transport, and about wave characteristics. The existing knowledge of coastal engineering, CERB members agreed in 1964, precluded confident assessment of all the research areas the CERC programs should cover.[4]

Any major breakthrough in coastal engineering required the development of general theories precise enough to be applied at specific sites. In the case of coastal problems, wind-generated waves usually are the driving phenomena. Waves affecting the coast

can be generated across entire oceans. When these waves break, they set up currents along the beach. Many different interactions occur. The relatively short-term, back-and-forth currents of the waves are superimposed on steady currents along the beach, which vary across the width of the surf zone (the area of foamy water caused by waves upon the shore). At a tidal inlet, ebb and flood currents interact with approaching waves and also with the coastal longshore currents. The waves take sand into the inlet, trying to fill it; the tidal currents try to keep flushing the sand out.[5]

Coastal conditions are more complex than those of a flowing stream. In river engineering, hydrology provides basic data sets, which are relatively easy to acquire. Rainfall measurements can be obtained, and more people are at work in hydraulic research. It is true that rivers differ from one another, depending on the geology and topography of their basins. However, someone traveling 500 miles down the Mississippi River from Cairo, Illinois, would see fewer differences than along 500 miles of Atlantic coast stretching south from Boothbay, Maine. Data basic to coastal engineering have a different source and are much harder to obtain.

Behavior at a tidal inlet depends on the length, width, and depth of the tidal prism. Pamlico Sound, North Carolina, is large, but it is so shallow it takes a long time for the tide to travel across. Puget Sound, in Washington, is deeper and behaves differently. In river engineering, techniques and solutions used at one place can be applied to problems elsewhere. Because wave environments differ more, coastal research is more site specific. In addition, to describe wave phenomena, one must use the complicated mathematical techniques developed by or for electrical engineers, time series analysis, and Fourier analysis and transforms.[6]

Beach Protection

The beach system consists of the unvegetated face of the shoreline extending from the lower edge of the dunes seaward. It includes the backshore (the dry beach lying adjacent to and below the dunelands), the foreshore (the wet beach extending to the low-water mark), the nearshore (the submerged beach extending seaward as far as the force of the waves reaches the bottom), and the bar (an offshore ridge that may emerge at low tides but is mostly or permanently submerged). The entire complex is a sand storage system. Reacting to wave energy, each part of the beach receives, retains, and gives up sand.

The Beach Erosion Board's early efforts to protect beaches relied mostly on a standard solution of constructing groins to trap the sand and bulkheads to check erosion.[7] However, continuing investigations suggested something better was needed. Research in Florida in the 1930s suggested that any "fixed line of defense against waves" should have a "reasonable expanse of sand in front."[8] In the 1940s, the BEB urged local interests to construct projects large enough to protect areas extending headland to headland or inlet to inlet and recommended artificial nourishment of the beach.[9] By the 1950s, when research had revealed the site-specific features and complex energy systems of shorelines, the BEB recommended compiling a chronological history of a site prior to any construction.[10] Researchers also knew that structures played no role in stabilizing beaches.[11]

The opportunity to test the new technique of beach replenishment on a large scale came in the Harrison County, Mississippi, project. It consisted of building a new beach with six million cubic yards of sand and repairing a seawall to protect a highway.[12] In 1951, soon after the initial fill had been placed, wave action eroded what had been planned as a permanent beach. Corps project managers then opted for the continual replenishment of the beach.[13] From this project, the Beach Erosion Board concluded that periodic replenishment of the sand was a more effective and economical solution than using groin fields. Thereafter, the Corps declined to support any legislation that would allow Federal financing of seawalls, bulkheads, and groins designed to protect beaches. Instead, the Corps favored changes in the wording of the law that would broaden the definition of project construction to include the deposit of sand fill.[14] In 1956, Congress enacted the legislation the Corps recommended.[15]

After 1956, the number of beach restoration projects increased rapidly. Early advances in beach nourishment techniques culminated in 1966 with a successful test program using a hopper dredge at Sea Girt, New Jersey, and completion of the replenishment of Redondo Beach, California, in 1969. The latter project demonstrated that technology was sufficiently advanced to make sand and gravel on the shallow parts of the shelves an exploitable resource. The approach also could be as economic as such

other replenishment methods as truck hauling and drag scooping.[16]

Major CERC Research Programs

Beach Erosion Board studies had addressed questions in a number of general categories: the effects of tides and waves on shore erosion and accretion, sediment movement, inlet and estuary dynamics, the design and siting of structures to stabilize the shore or to protect it from storm waves and surges, the construction and improvement of harbors and channels, and the effects of structures on the shore. The investigations underscored the fact that much had to be learned about the coastal zone. In launching CERC, therefore, the members of the Coastal Engineering Research Board determined they would do two things. First, they would divide CERB meetings into an executive session dealing with organizational matters and technical sessions examining the state of knowledge in various fields to assess future research requirements. Second, they would focus CERC's initial research activity primarily on wave action and sediment movement. The need was obvious. Only one document covering the broad Federal oceanographic research program had been published, and Government experts thought it lacked substance and was poorly written.[17]

Sediment transport and wave action are linked closely. Material can move completely within the fluid (suspension), at the fluid-bottom interface (bed load), or within the sediment (creep). Water stress on the bottom due to turbulence and wave-induced velocity causes sediment in the surf zone to move with each passing breaker. High velocities under breaking waves entrain sediments so they can be transported along the shoreline by longshore currents. Because waves generally approach the coast at an angle, a part of the wave energy is directed along the shore, driving the longshore current. Coupled with the entrainment capacity of shoaling waves, this current is the major force moving sediments at the coastline.[18]

On any beach, erosion or accretion is the net effect of all forces acting there. Understanding what is happening at any given point on the coast requires ascertaining the net effect of several interacting forces. Measuring them gets complicated. Generally, understanding the aspects of a particular physical process is made easier by measuring only one force at a time. Researchers usually regard the largest scale under investigation as current motion. Smaller scale phenomena are viewed as irregularities or turbulence. Not uncommonly, a particular flow phenomenon is the current motion in one investigation and turbulence in another. A researcher with a primary interest in ocean currents, for example, considers waves as turbulence while a researcher interested in wave direction views currents as turbulence.[19]

Morrough P. O'Brien, CERB's Dean, felt that CERC's first priority should be to determine the relation between the littoral drift rate and wave energy because it governed the movement of sediment transported by wave action and was associated with the many erosion problems along the 84,000 miles of U.S. coastline. O'Brien wanted the four Corps agencies involved in coastal engineering to develop a ten-year program to investigate all facets of the American coastline, broken down by major coastal geographic regions.[20]

While the CERC staff plans were less grandiose, they were still ambitious. Research would cover five general areas: wave and water level characteristics; sediment transport; erosion and shoaling; functional and engineering design of coastal projects, including their effects on the physical and biological environments; and the mitigation or enhancement of these effects through ecological engineering. Investigations would be conducted through seven specific research programs–Waves and Wave Action, Coastal Processes, Inlet Dynamics, Coastal Ecology, Field Data Collection, Engineering Design, and Technical Services.[21]

Each one of the seven CERC programs would address a specific Corps need:

1. The Waves and Wave Action program aimed to describe and then predict the actions of the dominant forces acting on coastlines.

2. The Data Collection program would acquire information on wave height, period, and direction at 98 coastal locations in the continental United States, Alaska, and Hawaii, and also off shore. The program would provide the climatic or statistical data needed on a geographic basis for coastal engineering planning and design and would cost an estimated $12,233,000.

3. The Coastal Processes program sought to describe and predict the interactions among materials that make up the coasts and the forces that act upon them. It included gathering data on sediment sup-

plies for beach nourishment projects and envisioned coastal surveys costing a projected $67,549,000. This program would take some 12 years to complete.

4. Inlet Dynamics involved the study of the hydraulics of flow through coastal inlets and the reaction of inlets and adjacent sandbars to these forces. New testing facilities would be needed for this work.

5. The Coastal Ecology program, which was added near the end of the decade, aimed at assessing the effects of engineering projects on the biological environment and lessening or precluding detrimental ecological effects.

6. The Engineering Design program was the centerpiece of the CERC research plan. To CERC staff, engineering research had little value unless the results were translated into practical engineering design techniques and made available to engineers through CERC publications. Part of this program included monitoring and evaluating completed coastal structures and projects to determine their effectiveness, maintenance costs, and expected life.

7. The Technical Services program would provide advice on complex coastal engineering problems, allowing others to draw on CERC's unique experience.[22]

Data Collection

Through its 20-year existence, CERC's major activity was assembling an immense database from measurements taken at numerous sites. As had the Beach Erosion Board, CERC hoped that an in-depth understanding of phenomena at diverse sites would enable researchers to formulate universal theories that could be applied to specific problems.[23]

Beach Erosion Board data collection programs dated back nearly three decades. A 1934 study at Wrightsville Beach, North Carolina, based on data gathered in the widely scattered years of 1857, 1887, and 1927-1932, established the need for more and better data.[24] A 1934 study of Hollywood Beach, Florida, noted that the beach had undergone discontinuous periods of erosion and accretion with the most rapid erosion occurring during tropical storms. Because investigators had no data, they could not determine when specific changes took place.[25]

A 1937 investigation of erosion at Blind Pass, Florida, also suffered from a lack of firm data.[26] At Daytona Beach, in 1938, BEB investigators had to rely on existing records and the memories of residents; the data they turned up contained disconcerting discrepancies.[27] The probable effect of a Corps harbor improvement project was noted in a 1935 report on beach erosion at Folly Beach, South Carolina. However, without data the causes of erosion could not be determined.[28] For a 1940 investigation of St. Simons Island, Georgia, by contrast, the board benefitted from a vast data collection, the result of a state report describing the geology of the Georgia coastal plain.[29] Overall, as Thorndike Saville, Sr., noted in a 1942 article, the absence of basic information greatly inhibited the work of the BEB.[30]

To begin to remedy the situation, the Beach Erosion Board established a wave gaging program in 1948. Partly because the BEB had begun its work with a study of Cape May, the 120-mile New Jersey shoreline became the shore processes field laboratory, with two gages operated at Atlantic City. In 1952, the BEB introduced regional studies into its research program. As initially conceived, regional

CERC Employee Setting a Wave Gage

reports would discuss geomorphology, littoral materials, waves, currents, and wind forces. The reports also would describe and analyze the effects of man-made structures and works. A region was to comprise one of the larger physiographic units of the shoreline, such as Sandy Hook to Delaware Bay or the St. Johns River to Government Cut at Miami Beach. The BEB staff expected that as coastal problems arose in various areas, the regional study would furnish the basic information needed to address them.

In 1954, the board established a surf observations program in cooperation with the Coast Guard. Initially, 27 Coast Guard stations located along the Atlantic, Pacific, and gulf coasts made visual observations of the surf at four-hour intervals, visibility permitting. The beach-monitoring program, begun after the March 1962 storm, surveyed about 90 profile lines on eight beaches between southern New Jersey and Rhode Island to relate storm and tide conditions to specific changes on the beaches. This represented a first step toward developing a storm-warning system for low-lying coastal communities. The study also examined the behavior of beach sand in two beach replenishment projects. The beach-monitoring program later was extended to every east coast state except Delaware and South Carolina.[31]

Acquiring data was a slow process. As late as 1974, the South Atlantic Division – ranking second in the Corps' Divisions in shoreline responsibility with over 15,000 miles of coastline bordering the Atlantic, Gulf of Mexico, and Caribbean Sea – faced a variety of wave and wave-related problems ranging from oscillatory wave forces to catastrophic hurricanes with little or no wave gaging data.[32] One reason was the limited number of acquisition sites. While the original data collection program proposed 98 stations, CERC scraped by with 21 at 17 locations. Almost all the sites selected represented a compromise between optimum placement and the practical considerations of finding suitable places to install and maintain the gages. Funding, limited manpower, and the lack of wave-gaging technology–which CERC continually bemoaned–also inhibited progress.[33]

Initially, researchers measured wave climates (the normal behavior of waves at a specific place over a period of time) by putting gages on fishing piers and at other locations to trace wave heights and wave periods. Data had to be analyzed by hand. (Significant height equals the average of the highest one-third of the waves present.) The results were important. By 1965, using wave-gaging stations and historical daily weather maps, the daily wave patterns along much of the ocean coasts and three of the Great Lakes had been measured and summarized in monthly and yearly statistical tables. In the 1960s, CERC began converting wave stations to digital records. When computer-based analysis techniques were developed, the measurements were easier to analyze, and the results could be published more quickly.[34]

In 1967, CERC made arrangements with the Galveston and Honolulu Districts to initiate basic data collection programs for selected shore segments along the Texas coast and the Hawaiian Islands. The same year, the Corps and the State of California began a cooperative program to collect wave records with instruments at selected locations. Expanded in 1977, the California program sought measurements at about 100 locations. The CERC used 60 pressure transducers located on existing fixed structures and some 40 wave-measuring buoys located in water depths of about 200 feet or less. The resulting data and that from other programs of the State of California, the Navy, the National Oceanographic Survey, and private concerns were stored for future use. The program also provided extensive information on California coastal processes to improve project planning and refine designs.[35]

Elsewhere data were collected manually. The Littoral Environment Observation (LEO) programs used simple instruments: a stopwatch or ordinary wristwatch, a wire wind meter for measuring wind speed and direction, a simple topographic level for making beach slope measurements, a hand level to make beach profiles, and a bucket of dye to throw into the water to track the longshore current and measure its velocity. The program relied on people who were on the beach most of the time, such as park rangers, lifeguards, and lighthouse keepers.[36]

Data acquisition also involved field collection designed to help understand how wave-induced littoral currents transported suspended material. This was to discover the effects of erosion because, with a few exceptions, the dominant erosive force was wind-generated wave action and the loss of beach material was essentially permanent. The critical zone for study extended from the 50-foot depth contour to the shore. Early on, CERC had published a technical memorandum on the effect of wave action on the transport of bed material. However, the lack of knowledge about turbulence at the wave boundary

layers and the lack of suitable suspended sediment measuring techniques made predicting the distribution of suspended sediment extremely difficult.[37]

To minimize the requirement that personnel and equipment be onsite for specific periods of time, CERC experimented with two photographic techniques in which commercially available cameras with automatic lenses were programmed remotely to shoot selected lengths of film at predetermined times. After a pilot study on Lake Michigan in 1971, CERC extended the visual observation program to the Great Lakes and ultimately to 20 state parks. Equipment was studied and improved, and better data were recorded.[38]

To understand the sediment movement processes better, CERC and the Atomic Energy Commission jointly sponsored the multi-agency Radioisotopic Sand Tracer (RIST) program. Initiated in 1967, the program was to develop techniques and technology to trace nuclide-labeled particles in the marine environment while carrying out field experiments in different coastal environments. In the initial three-year program, the Corps obtained data on sand movement patterns and developed computer programs that constructed the resulting surface. The goal of CERC was to accurately measure the short-term littoral rate and sediment volume and then develop a mathematical model to calculate them. The first requirement was to develop a tagging process that could use sand indigenous to a particular geographic area but that would not alter the sand's hydraulic characteristics. Second, CERC had to design a vehicle capable of operating on the beach and in the surf nearshore to depths of 100 feet of water while simultaneously detecting multiple tracers.[39]

By 1974, CERC's coastal field data collection efforts were being directed toward satisfying requirements in several important areas. Wave data obtained from gages installed at selected coastal locations would identify regional, statistical wave climatologies. These would be used to design and economically evaluate projects. Visual observations of surf conditions and nearshore current patterns, obtained between gage sites, would provide estimates of sand transport rates along beaches and additional wave data for nearshore areas.

The CERC hoped these observations would allow the gage data to be interpolated and transposed to intermediate locations or locations where complex hydrography precluded its direct application. Records of long-term seasonal and storm-induced beach, dune, and nearshore profile changes would enable researchers to quantify erosion and accretion rates and monitor the onshore-offshore movement of sand. Correlated with local wave statistics and nearshore current patterns, these data would enable designers to evaluate potential beach restoration and nourishment projects. Data collection also included information on accessible offshore areas of sand suitable for use in beach nourishment projects and the availability of any aerial photographs of coastal areas.[40]

Laboratory Modeling

Field data collection and laboratory studies are integral parts of the same research process. When Thorndike Saville, Jr., went to work for the Beach Erosion Board in 1949, for example, his first year was spent on the West Coast doing wave hindcasting for the South Pacific. Ultimately, Saville was able to develop techniques for using early mathematical formulations and models. One long-term effect of his work and that of other researchers was to indicate the importance of the South Pacific swell.[41]

Laboratory research advanced theory. A long-term research project of the BEB, taking from eight to ten years, had examined freeboard for dams and levees on inland rivers. The question addressed was how high a wave would run up on structures under different conditions. The results were important to dam and levee design, which represented a substantial portion of the Corps' project work. In small-scale tests in the BEB laboratories and in other tests at the Waterways Experiment Station, researchers developed curves to predict the wave runup for a field condition. The salient question was how well the laboratory modeled. Researchers investigated this by testing waves ten times larger in a large tank. The results turned out to be reasonably close, and from there data researchers developed techniques for adjusting the two data sets. Using this information, researchers derived methods for translating the monochromatic results to nature's spectrum. The study was the first of its kind in the field. The research advanced theory in the areas of wave generation, wave runup, and wave overtopping and in the techniques of wave measurement, all of which applied to the coastal zone.[42]

CERC Laboratory Facilities

Laboratory modeling and testing allowed researchers to simulate natural processes under

controlled conditions. Some questions could be answered by studying available alternatives. In the late 1970s, for example, CERC's Coastal Processes and Structures Branch conducted laboratory tests of irregular wave runup on riprap-protected dikes. The problem was that a number of diked enclosures along the shores of the Great Lakes containing materials dredged from harbors and channels and armored with riprap had to be protected from wave overtopping (which could stir up the sediment within the enclosed lagoon). Thus, each dike had to be higher than the maximum breaking wave. Designing individual enclosure dikes was complicated by the fact that the intensity and direction of the wave attack varied considerably and uniquely around each one. Determining correct crest elevations and cost-efficient design characteristics was important because the cost of a dike exactly increased in proportion to its height.[43]

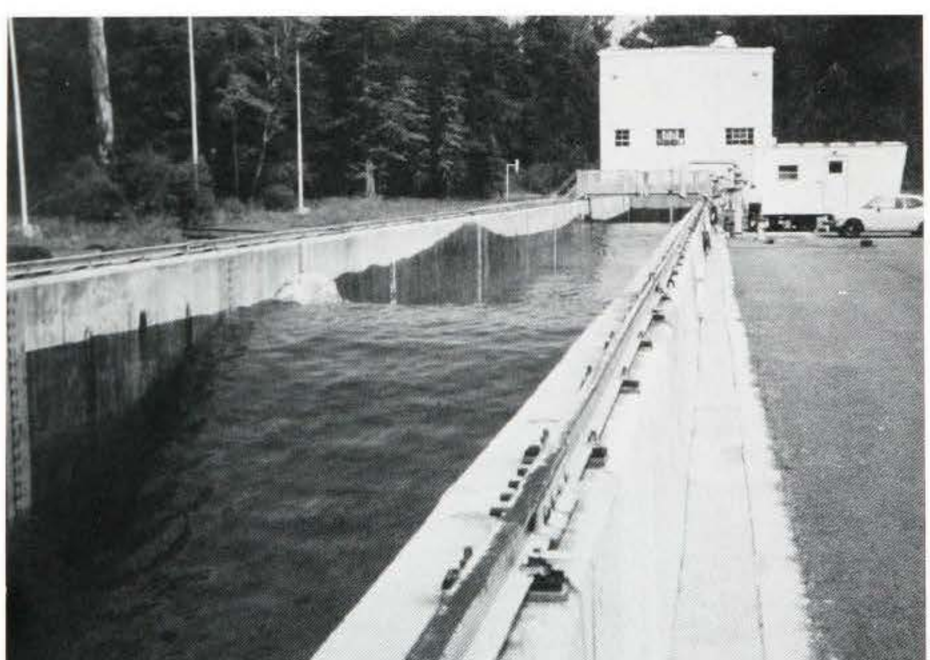
Model testing also could assist in finding formulas that had general application to design. Whenever a coastal engineer has to build a structure across the shoreline or go farther seaward, or has to design for vessels coming into a large port, it is important to determine how far seaward the waves move sediment. In the past, designers had used the rule of thumb that a 20- or 30-foot depth was an appropriate limit to cut off condition surveys.[44]

To obtain more precise information, CERC investigations looked at the dominate wave zone that extended from the 50-foot contour to the shore. To compare characteristics, field investigators measured material in suspension along unaltered coastal segments and in segments affected by engineering works such as groins and harbor jetties. From the raw data generated in CERC's RIST program, computer research determined sand movement patterns and programs to reconstruct surface data.[45] Researchers then set to work on developing a mathematical model to calculate the littoral volume drift rate.[46]

Sediment analysis and testing were important laboratory projects. When coastal waters are laden with suspended solids and the tidal range is high, significant harbor shoaling often occurs. To design harbors effectively, engineers have to determine the shoaling rate and evaluate the relative importance of factors involved in the shoaling process. Lack of knowledge about the characteristics of turbulence at the wave boundary layer, exacerbated by inadequate suspended sediment measuring techniques, precluded accurate prediction of the vertical distribution of suspended sediment. Hence CERC tested six different suspended sediment techniques then available and reported on the most promising.[47]

Other CERC investigations suggested that sediment began to move under wave action when the bottom particle velocities were somewhere between one-half and three-quarters of a foot per second. The task involved determining from surface observations where the seaward limit of the critical bottom particle velocity lay. The answer depended on knowing the wave height, water depth, and wave periods. That information would relate to the bottom-particle velocity conditions that would move sediment. A CERC work unit conducted tests in the CERC-funded water tunnel at the National Bureau of Standards in Gaithersburg, Maryland.[48]

The large wave tank was the major research facility of the BED, and later of the CERC. It was



CERC Large Wave Tank

635 feet long, held approximately a million gallons of water when filled to test level, and could generate 6-foot breakers. With the tank, researchers could study beach equilibrium profiles, wave runup and overtopping, and the stability of structures designed to resist the sea's battering.[49] When CERC moved from Dalecarlia to Fort Belvoir, a new large wave tank was constructed. It used the old monochromatic wave generating mechanism that had been Army Ordnance surplus in 1953.[50] The drive converter was updated in 1973. In 1977 a digital wave runup system, designed and built at CERC, was installed. The tank then could accept a variety of sensors to test for wave height, runup, and generator blade position and could produce data compatible with a computerized data acquisition system. With its monochromatic generator, the wave tank could produce long-period, big waves that replicated the long, low Pacific Ocean swells affecting the California coast. Well into the 1970s, the large wave tank employed the most modern research technology.[51]

Experimental facilities and equipment became increasingly sophisticated during the two decades of CERC's independent existence. Equipment costs also rose rapidly. When CERC moved to Fort Belvoir, a new shore processes test basin had to be built. It cost $3.7 million when finished in 1972. In the late 1970s, the estimated cost of installing in the SPTB a modern multispectral wave generator that would approximate a wider variety of conditions ranged from $700,000 to $1.6 million. (CERC's 96-foot wave tank generator, completed in 1958, had cost $3,200. When acquired in 1966, CERC's 72-foot wave tank generator, which could produce the irregular waves that more nearly approximated natural conditions, cost $29,100. Portable wave generators for the original basin at Dalecarlia had cost $10,000 each.) By 1980, when the shore processes test basin at Fort Belvoir required new wave generators, the estimated cost of installing new equipment was $700,000 and for generators that could produce a tidal system, $200,000.[52] The constantly increasing cost of equipment was to have important consequences for CERC.

Replicating nature in the laboratory was an arduous task. A typical CERC laboratory test on littoral transport involved generating waves with specific periods, heights, and angles of approach in a specific water depth. However, physical model tests were difficult to carry out. For example, sand particles are small, but they are too large for model study, and sediment particles smaller than sand grains either behave like clay or disperse like flow. Experimenters tried a variety of materials before they found a specially designed coal that could be used to simulate sand.[53]

Duplicating nature in laboratory facilities was difficult in other ways. In the early 1960s, researchers tested the littoral movement of sediment in the shore processes test basin. The research design required controlling the height of the waves generated in the SPTB, but the waves varied. Adding wave absorbers did not improve matters sufficiently; nor did installing a large absorber around the entire outer portion of the tank to dampen all wave action within the outer basin. Next, researchers removed the wave guide-walls from the test area and doubled the number of wave generators to four, increasing the length of the generated wave. They placed rubble absorbers around the outer perimeter of the tank to dampen all reflections. The changes reduced but did not remove the problem. After two years of analysis, researchers discovered that reflection from the tested beach was causing the variation. Four years of work were required to get the problem completely under control.[54]

Researchers had similar problems with studies of littoral transport. When conducting a typical research study or model test, a research engineer established particular wave conditions and investigated their effect. The researcher expected the wave conditions to remain constant. But once the experiment started, wave height varied in both time and position. The CERC eventually established a Coastal Processes Branch (CEB), one of whose aims was to improve its capability to conduct movable-bed research experiments of wave action on sandy beaches.[55]

Each series of experiments involved considerable time and expense. The search for theoretical applications needed to be reconciled with the search for answers to immediate problems. An example was the Corps project at the Masonboro Inlet, North Carolina, which was not functioning as hoped. In trying to simulate the dynamics of tidal inlets, researchers first planned to develop and test a simple inlet model and then to develop and test a model of a complicated inlet.

In 1969, the CERB recommended that CERC skip the first stage and go on to study a complex inlet simulation using Masonboro Inlet as a prototype. In 1971, in a related study, CERC applied techniques

developed in the RIST program to determine the effect of a weir jetty on the transport of sand across Masonboro Inlet. The experiments served the multiple purposes of solving a problem at the inlet, improving inlet modeling, and developing sand tracing experiments.[56]

Field Research Facility

As stated earlier, theoretical modeling sought a practical way to integrate field data with conclusions drawn from laboratory research to predict wave action. As CERC acquired new facilities and new computer technology became available, researchers had access to better data, and the modeling techniques became more accurate and prominent.

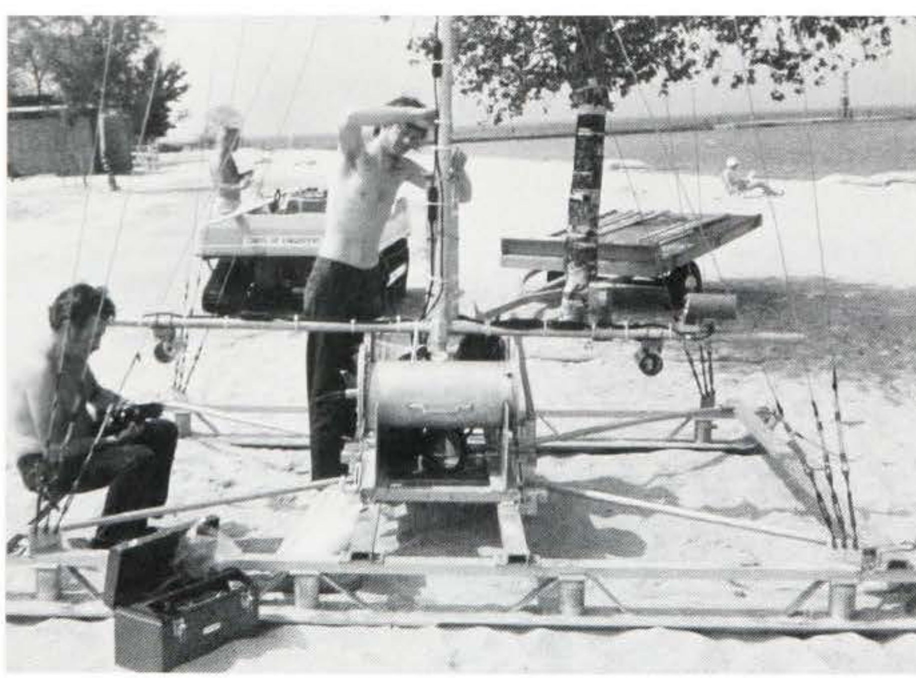
Two types of primary field research studies were conducted at the Duck Field Research Facility. An ongoing study produced some 35,000 wave, current, meteorological, and bathymetric data records and 1 annual and 12 monthly data reports summarizing oceanographic and meteorological conditions. The other type of study involved collecting wave and survey data to determine the processes controlling sediment transport characteristics, beach erosion, and profile change during storms. As new technology appeared, CERC staff applied it to data at the Field Research Facility.

In February and March 1977, CERC participated in a cooperative experiment involving aircraft overflights and surface measurements related to the testing of microwave sensors. The experiment allowed the prelaunch testing of microwave instrumentation during various wind and wave conditions for SEASAT-A, a satellite designed for oceanographic purposes and launched in June 1978. The experiment particularly interested CERC because of its potential to provide data on wave direction, wave height, wind field, and ice mapping. Through August and September, CERC collected aircraft and in situ instrument data on wave height, wave period, current direction, wind velocities, and sediment characteristics to validate the SEASAT-A oceanographic data in the coastal zone.[57]

Ultimately, the combination of voluminous data, new technology, and researcher expertise led to breakthroughs in understanding. The DUCK-X experiment, which involved scientists from seven countries and many organizations, measured waves ranging from deep water to the shoreline and collected a wide variety of data. From it, researchers developed a new spectral technique that related significant wave height to standard observational measurements, making it possible to determine available energy at each wave period.[58]

Problem Areas

While data collection generated usable information, it was expensive, time consuming, and plagued with problems. Established techniques made assembling enormous amounts of wave data possible, but observation and analysis procedures were not always consistent. Observers 500 meters apart would not necessarily make the same wave observations. In some cases, data differed when collected from gages only 30 meters apart. Even when ocean data were available, researchers could not relate the data to the breakers. Difficulties in obtaining wave records at most East Coast beaches forced researchers to simply record beach profile changes in order to arrive at



CERC Personnel Preparing Instrumentation Sled

quantitative measurements of beach fluctuations during typical seasons.[59]

The CERC staff had assumed that District and Division engineers could and would apply usable information from the CERC data bank to solve design problems. Rarely was this the case. The paucity of statistical data on both offshore and near-shore wave conditions and the absence of sufficient analysis handicapped the engineers who needed current and timely data for a project. Rarely were District and Division engineers able to adapt the CERC data bank to their needs. Nor did CERC researchers find the means to succeed in translating data to the formulas that could be used by engineers to solve site-specific problems. Therefore, CERC concluded that more data were needed to solve design problems and to develop the long-sought descriptive and predictive theories.[60] The CERB agreed. The accumulation of more data, CERB reported in 1976, had become "a national imperative." The board recommended that the Federal Government establish a national wave data collection program comparable to the national streamflow data program.[61]

IV

MAJOR CERC PROGRAMS AND PROJECTS

An important aim of coastal engineering design is to create a stable shoreline or, if one already exists, to maintain it. The condition of a shoreline is determined by the movement of sediment, called littoral transport. The two include onshore-offshore transport, which occurs when sediment moves perpendicular to the shoreline and longshore transport, which takes place when sediment moves parallel to the shore. If the rate at which sediment is supplied to the shore equals the rate at which sediment is removed, the shoreline remains stable. If not, the sediment must be replenished through beach nourishment projects.[1]

Beach Nourishment Techniques

As beach nourishment became more common, lagoons, wetlands, and inland sources could not supply sufficient suitable sand at feasible prices. Also, sources of fill material became difficult to find. By 1964, CERC had the capacity to compare natural material (sediment at a project site) with different types of borrow material (sediment brought to the project site from elsewhere) to quantify and predict sediment losses after beach nourishment. In 1964, CERC initiated its Sand Inventory Program, a search for exploitable deposits of sand, mainly from offshore. The CERC also undertook research to refine techniques for matching fill with beach sites.[2]

The first survey, off the New Jersey coast, located suitable beach-fill material in waters from the 75-foot contour landward to a water depth of about 15 feet. Geophysical instruments could not produce reliable results in depths under 15 feet at the time, however, and the only economical coring equipment available was too hazardous to operate within the 15-foot depth. Technological improvements that would enable investigators to work farther inshore did not become available until later.[3]

By 1967, CERC had collected 1,558 statute miles of profile data from the New Jersey program, 2,600 miles of seismic reflection profiles and sediment core data from the East Florida Continental Shelf, and approximately 2,200 miles of seismic profiles of the New England coast from Portland, Maine, south to Long Island Sound. The explorations pinpointed suitable sand deposits, which proved to be in greater supply than expected, and yielded information on the bottom morphology and sediment composition of the bottom shelf.[4]

To make beach nourishment widely feasible, designers needed a simple, economical method of beach nourishment using the offshore sand deposits as the borrow source. By 1967, the Operations Division, OCE, had under way a comprehensive research and development program focusing on new equipment and procedures to determine their applicability to Corps operations. Ultimately, the various types of sand-mining (dragline, self-propelled bottom-dump, scrapers, diesel shovels, etc.) for commercial purposes would be classified by littoral zone locations.[5]

In 1976, the Corps tested a new split-hull dump barge, the *Currituck*, which was capable of transporting and depositing sand in the nearshore zone. Split-hull barges had been used in Europe for a number of years, but the *Currituck* was the first self-propelled barge. In the initial test, the side-casting dredge *Merrit* loaded the *Currituck* with material dredged from the entrance channel in New River Inlet, North Carolina. In 20 working days, the *Currituck* placed about 35,000 cubic yards of material in the foreshore zone immediately south of New River Inlet.[6] By now, CERC researchers were investigating other means of transferring offshore sand to the beach zone, including submarine dredges, offshore self-elevating platforms with dredging equipment, pipeline dredging plants capable of operating in the

Before and After View of Beach Nourishment Project at Westhampton Beach, New York, 1969

ocean environment, and pipeline delivery systems using jet pump and eductor principles.[7]

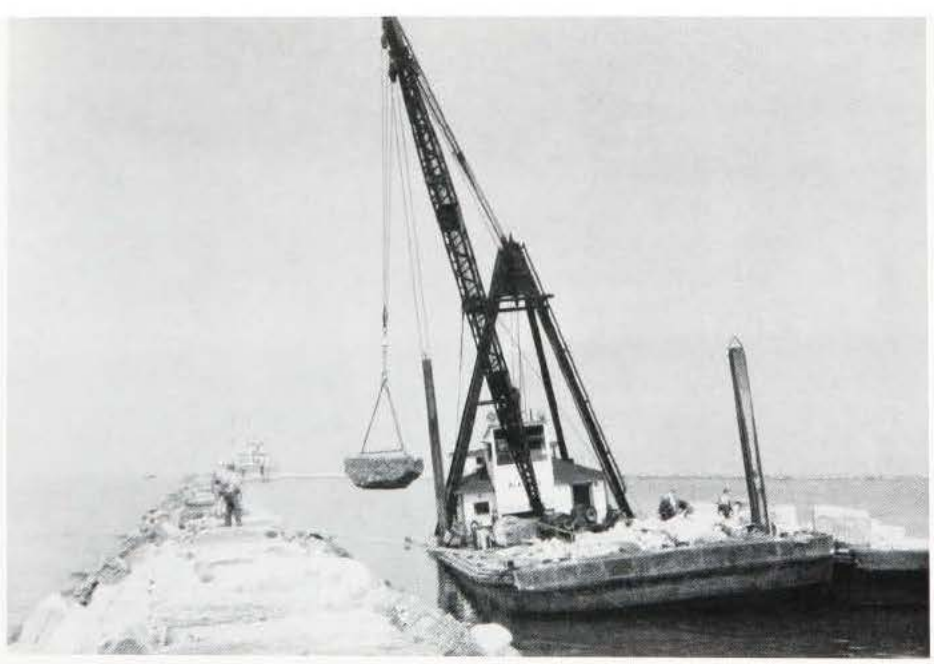
Groins, Jetties, and Breakwaters

Traditional artificial methods of arresting shore erosion depended on either reducing the wave energy at the shore, as does a revetment, or interrupting the longshore current and trapping sand, as do groins. Through the end of the World War II, to stabilize the beaches and control erosion, engineers erected seawalls, revetments, bulkheads, groins, and breakwaters.[8] In dealing with coastal erosion problems, engineers invariably selected the groin as a means of protection, to be used either separately or in conjunction with other methods. Yet, despite years of use, groins were probably the least understood structures employed for shore protection. Coastal engineers were unable to agree on groin designs and emulated techniques that had worked elsewhere. Their effectiveness depended on a number of factors: groin length, height, spacing, permeability, adjustability, and orientation.[9]

To understand how various types of groins functioned, CERC began in 1965 to study the feasibility of conducting field studies to measure water and sand flow over, around, and through experimental, adjustable groins under various wave conditions. The effort led to installing a Prototype Experimental Groin Facility on the Pacific Missile Range property at Point Mugu, California, approximately 65 miles north of Los Angeles. The Los Angeles District had begun a littoral environmental data collection program there. The facility had a pier extending seaward with the six experimental adjustable groin configurations installed on its north side.[10] Practical applications of this research bore fruit in the groin and sand replenishment projects at Newport Beach, California; Presque Isle Peninsula on Lake Erie at Erie, Pennsylvania; and Prospect Beach, Connecticut, on the shore of Long Island Sound.[11]

Jetties long had been used to keep harbor entrances clear of littoral drift. However, interruption of the natural bypassing of littoral drift often caused downdrift shores to erode. Sand bypassing, the technique of moving sand from the accreting side of a jetty to the eroding side where it was again available for transport along the downdrift shore, was one way to restore the sand balance. The Nation's first sand transfer plant had been constructed at South Lake Worth Inlet, the entrance to the port of Palm Beach, Florida. There, in 1927, a channel had been dredged and two protective jetties built. In 1936, the north jetty's capacity for impounding beach material on its north side was exhausted. Seeking to keep the channel clear, engineers raised the jetty and installed a small pumping plant with a pipeline across the inlet. The project's effectiveness led to the construction of another sand transfer plant.[12]

Weir jetty design combined both a jetty and sand bypassing in one system. Built from the shore seaward at the entrance to inlets, weir jetties are intended to maintain a safe navigation channel and to provide a deposition basin on the updrift side of the inlet to trap sand moving into the inlet from the adjacent shore. Weir jetties have a low sill elevation along part of their length. Sand is transported over this into the deposition basin by wave and tidal current action. Periodically, a dredge bypasses the sand that builds up in the deposition basin in the lee of the jetty to downdrift beaches to restore the sand lost by erosion. Corps engineers first conceived the weir jetty system



Repairs to West Arrowhead Breakwater, Oswego Harbor, New York, 1959

to stabilize the habitually migrating inlet at Masonboro, North Carolina.

Between 1966 and 1972, the South Atlantic District constructed other weir jetty projects at East Pass, Florida; Perdido Pass, Alabama; and Ponce de Leon Inlet, Florida. Because the system had to remove the material intercepted by the jetty quickly and then deposit it at the same rate, weir jetty construction had to be planned carefully. The responsibility of CERC was to develop techniques for predicting shoreline changes resulting from weir jetty construction, compute littoral transport, and design weir jetties.[13]

Like groins and jetties, breakwaters were used worldwide as wave energy dissipaters. The Santa Monica, California, breakwaters were constructed to provide a sheltered area for a small-craft harbor of refuge. Farther north, breakwaters at Channel Islands Harbor and Ventura Marina were designed to form a littoral barrier. The ability of breakwaters to minimize wave energy reaching the shore suggested they could be employed to stabilize beaches, particularly where the cost of beach fill was prohibitive. Offshore breakwaters in Singapore, at Fumicino, Italy, near Tel Aviv, Israel; and at San Juan, Puerto Rico, had demonstrated the technique.

In the United States, offshore breakwaters constructed in 1931 to protect the seawall and backshore area at Winthrop Beach, Massachusetts, had helped control erosion. In 1976, CERC's Design Branch began a program to provide functional and structural guidelines for the use of offshore breakwaters to stabilize the shore. The CERC work unit looked at the structure variables of height and length, crest width, spacing, and distance off shore; the hydraulic variables of water depths, range of water-level fluctuation, height, period, and direction for both the incident and transmitted waves; aspects of the transmitted wave, including the effect of wave overtopping and wave diffraction; and sediment variables such as the beach slope, shore alignment, and the longshore and on shore-offshore components of the littoral transport.[14] Segmented offshore breakwaters could protect shores from erosion by both reducing wave energy and interrupting the longshore current to trap sand. The Corps' Lakeview Park Project, constructed in 1977 at Lorain, Ohio, was an early example. Designed to protect the shore and provide and protect a public recreation beach, it consisted of three 250-foot-long detached breakwaters, two groins (one 150 feet long and one 300 feet long), and an initial 100,000 cubic yards of beach fill. Although the Corps had predicted annual maintenance at 5,000 cubic yards of sand a year, until 1980 no replenishment was needed.[15]

The CERC conducted floating breakwater tests in the laboratory and constructed several projects to assess the feasibility and economic merits of various construction techniques. Two sections of breakwater were constructed using a design developed by the Goodyear Tire and Rubber Company at Pickering Beach, Delaware. Another prototype installation, constructed at West Point in Puget Sound, consisted of two sections of concrete box floating breakwaters, two pole and tire breakwaters like those used on the East Coast, and three forms of log or wood-type breakwaters.[16]

National Shoreline Study

In the mid-1960s, the National Association of Soil and Water Conservation Districts spurred a broad movement for either legislation authorizing Federal protection of affected properties or a ruling from the Internal Revenue Service making private

Floating Breakwater at Ketchikan, Alaska

costs for erosion control tax deductible. Conversations between representatives of the association and the OCE staff prompted the Corps to review its coastal erosion program. The talks also raised the difficult issue of affording the same Federal protection of private property along the coast as for public land.[17]

The National Association of Soil and Water Conservation Districts' proposals bore fruit when Maryland Senator Joseph D. Tydings agreed to support legislation to secure the association's aims. Personnel in OCE worked with Tydings' staff to draft what became Section 106 of the 1968 Rivers and Harbors and Flood Control Acts. They succeeded in shifting the focus from the narrow concern of protecting private property to the more general issue of analyzing the U.S. shorelines under the Corps' auspices.[18]

The National Shoreline Study (1970-1973) had mixed results. The CERC, which lent assistance, and OCE treated the study as a way to assess shore erosion problems and identify remedies; to target areas of priority; and to review existing policies, all with the aim of producing a guide to comprehensive planning for shore areas. The criteria and methodology used to assess the seriousness of the erosion problem were inconsistent across the various Corps Districts, partly due to limitations imposed by the time and funding Congress allotted for the work. During the National Shoreline Study, the Corps examined 84,000 miles of coastline, finding that about 21,000 miles or about one-quarter was significantly eroded.[19]

Some conclusions in the study were not well supported by data. The emphasis on defining and classifying erosion areas, the cost estimates for shoreline protection, and the attempts to identify areas requiring protection seemed to serve the interests of those calling for a far greater Federal role in project construction.[20]

Shoreline Erosion Advisory Panel and Projects

By defining the severity of coastal erosion, the National Shoreline Study heightened interest in additional Federal programs. Because approximately 75 percent of the affected property was in private hands, under existing law the Corps could not undertake projects to mitigate the damages. Changing the statutes to permit Federal financing for projects to protect private property appeared neither desirable nor feasible. The cost of fixing only 2,700 miles of eroded coastline was estimated at $1.8 billion in 1970, and Congress was unwilling to underwrite a protection program of this magnitude. However, based on the CERC studies of low-cost shore protection, Congress was willing to authorize $8 million to develop techniques that property owners could apply as they deemed appropriate. Congress's solution thus was to enact the Shoreline Erosion Control Act of 1974. It established a Shoreline Erosion Advisory Panel to provide general guidance and expert technical advice to the Chief of Engineers on the establishment, conduct, evaluation, and dissemination of results of the National Shoreline Erosion Control Development and Demonstration Program.[21]

The Shoreline Erosion Advisory Panel consisted of 15 nonfederal employees. It met six times between 1974 and 1976, recommended the criteria for selecting demonstration sites, and named 57 suitable sites along the coasts of the United States and the Great Lakes. The panel also listed useful erosion control devices to be tested and evaluated; compiled examples of institutional, financial, and legal project needs; and wrote guidelines for monitoring the functional and structural behavior of the devices installed at the demonstration sites. Most of the decisions and recommendations were based on CERC studies. On 16 November 1976, Chief of Engineers Lieutenant General John W. Morris named 16 coastal sites where low-cost erosion control measures would be tested, the first step of a five-year program. Six sites, all in Delaware, had been specified in the Water Resources Development Act of 1974, Section 54. The remaining ten sites, picked from the list recommended by the Shoreline Erosion Advisory Panel, were along the Atlantic, gulf, and Pacific coasts and the Great Lakes. Politics and the desires of the rquired local project sponsors constrained site selection and the types of projects to be constructed.[22]

The projects varied widely in the problems addressed. The Oak Harbor Demonstration Project at the Whidby Island Naval Air Station, in the Corps' Seattle District, exposed four basic types of revetment to the ocean. A sand-cement bag revetment protecting a 30-foot-high bluff at the eastern end of the project included two designs. Half the revetment was constructed of standard sandbags filled with concrete and placed while the concrete was wet. The other half was built of dry, ready-mix sand-cement of the variety available to homeowners at local build-

ing stores. A second revetment used at the site was a gabion structure. Here, two sections of timber bulkhead were constructed of vertical timber piles spaced approximately four feet apart with timber planks behind them. Tiebacks were constructed from logs that had been washed up on the beach. One section of timber bulkhead was of untreated timber; another section was creosote treated. The most unusual section of the project was a timber-pile, scrap-tire bulkhead.[23]

The demonstration project located at the Basin Bayou State Recreation Area on Choctawhatchee Bay, Florida, tested several new techniques with futuristic names. One was the Sandgrabber, at the western end of the project, which consisted of specially fabricated concrete blocks held together with steel rods to form a crescent-shaped breakwater connected to the shore at both ends. The Surgebreaker was a conventional offshore breakwater filled with sandbags. Another technique involved using a hogwire fence-sandbag bulkhead that was built by placing sand-filled acrylic and polyester bags behind a hogwire fence.[24]

Geneva State Park, Ohio, was the site of a different demonstration project. The park has a 10- to 15-foot bluff fronted by a beach that varies in width up to 50 feet. The project consisted of three offshore breakwaters, each approximately 100 feet long with a bottom elevation at 1-foot below low-water datum, and each constructed differently. The gabion breakwater was made up of wire-mesh baskets 3 feet wide, 18 or 36 inches high, and up to 12 feet long. When filled with stone and wired together, they created a massive structure to ward off wave attack. The Sta-Pods breakwater was constructed from individual concrete units similar in appearance to the armor units used in breakwater and jetty design. They consisted of a 2-foot-diameter cylindrical trunk with four legs attached at the midpoint and inclined downward at about a 45-degree angle. The Z-wall was constructed of reinforced concrete panels bolted together at the site. Each panel projected 14 feet perpendicular to shore and 7 feet alongshore. The 14 panels of the Geneva structure formed a breakwater 98 feet long, 14 feet wide, and 6 feet high.[25]

Beach Construction

One of America's rapidly growing recreation industries added a new dimension to the Corps' interest in beach restoration. By the late 1960s, the development of lighter, faster surfboards caused a boom in the sport of surfing. In California 600,000 surfers donned rubber suits and subjected themselves to the thrill of the waves and the pollution of man. No longer a seasonal activity, surfing extended over 365 days of the year. As visits to the surfing beaches averaged about 10 days per surfer, the economic effects were substantial. Based on the Corps' economic analysis figure of 50 cents per visitor day, surfing represented an annual benefit of $2 million in California. Moreover, the state manufactured over 50,000 surfboards which, with their accessories, represented a gross annual business of over $8 million by 1967.

While recreational benefits were not considered a primary project benefit in the formulas employed by the Corps in evaluating projects, this particular activity posed the question of whether or not the Corps should expand its coastal engineering role. Since 1933, as authorized by law, the Corps had concentrated on restoring and protecting, but not developing, beaches. Reflecting an appreciation of emerging public concerns, the Corps elected to expand into the area of beach development, but slowly.[26]

Problems on the Great Lakes

Beginning in the 1960s, rising lake levels threatened the lives and property of the nearly 40 million people who lived around the Great Lakes. By 1973, emergency flood-control measures were required. Because people had built too close to the water, protective projects would be extraordinarily expensive. In fact, studies showed there was not enough money in the Federal treasury to protect the shoreline. Moving people back from the shore was not feasible because the states lacked the funds to buy the land and put it into the public domain. So a large number of landowners planned to stay in the hazard zone. However, they looked to the Government to solve their problem.

Several agencies were involved in various coastal programs affecting the Great Lakes. Federal legislation authorized the Corps to implement emergency flood measures, but these did not include building emergency erosion works. Consequently, the Corps merely could recommend scientific approaches to managing the shoreline problems. Self-proclaimed experts also made a number of recommendations, and after listening to them, property owners installed all sorts of protective devices. Few worked.

Some in the Corps began to fear that the Environmental Protection Agency, which championed land-use regulations, would usurp the Corps' leadership position in dealing with coastal flooding problems. In addressing erosion problems on the Great Lakes, the Corps was in a politically difficult position. Occasionally, the most cost-effective solutions involved removing people from vulnerable and endangered shorelines. However, such proposals were public relations nightmares. Needing an initiative, the Corps called for a federal-nonfederal strategy. The proposed joint effort would include cooperation with states and municipalities in planning and developing both structural and nonstructural temporary and long-term protective measures. The Office of Chief of Engineers tasked CERC with providing technical advice on erosion problems; monitoring the performance of structures; and, in cooperation with the Great Lakes states, the Federal Regional Council, and the Great Lakes Basin Commission, examining the various alternatives. These included lake level regulation, land-use requirements, zoning and setbacks, land acquisition, relocation, structural protection, regulation of construction activities through permits, and insurance or damage reimbursement.[27]

The approach of CERC was to inventory sand deposits. It was based on an existing program. In 1968, the CERB, concerned with the need for shore protection in the face of rising water levels, had recommended beginning a sand inventory to obtain data on suitable sand deposits. However, the presidential order creating the National Oceanic and Atmospheric Administration (NOAA) (signed 3 October 1970) removed the U.S. Lake Survey from the Corps and established a Lake Survey Center under the National Ocean Survey. Following the change, the Lake Survey expanded its program to obtain cartographic data on lake bottoms such as reflecting topography, sediment thickness, sediment distribution, and subbottom geological profiles.[28] These organizational shifts delayed the start of CERC's Sand Inventory Program for the Great Lakes until summer 1975.[29]

The CERC began by making a seismic reflection survey of eastern Lake Michigan to locate and delineate sand deposits on the lake floor. Seismic reflection profiling, a technique widely used for delineating subbottom geological structures and bedding surfaces in seafloor sediments and rocks, is done by generating repetitive, high-energy sound pulses near the water surface and recording the "echoes" reflected from the seafloor-water interface and subbottom interfaces between acoustically dissimilar materials. Seismic-reflection surveys of marine areas are made by towing variable energy and frequency sound-generating sources and receiving instruments behind a survey vessel that follow predetermined survey tracklines.

One seafloor coring device was a pneumatic, vibrating piston coring assembly consisting of a standard steel core barrel, plastic inner liner, shoe, and core catcher, with a pneumatic driving head attached to the upper end of the barrel. The elements were enclosed in a tripod-like frame with articulated legs that allowed the assembly to rest on the seafloor during operation. Power was supplied to the pneumatic vibrator head by a flexible hoseline connected to a large capacity, deck-mounted air compressor.

New computer programs designed by CERC for handling large numbers of sediment samples shortened the time required to return usable information.[30] The CERC completed the field work for an Offshore Sand Source Study for eastern Lake Michigan in 1976. In 1977, CERC personnel, in cooperation with the Ohio division of the Geological Survey, surveyed 350 kilometers of the Lake Erie shoreline from the New York-Pennsylvania border to the western end of the lake and extending about 15 kilometers offshore. They collected 107 beach and lake-bottom sample cores over a two-year period. In 1979, CERC turned these over to the University of Toledo's Subsurface Data Center, where they are available to industry, Government, and academia for use in geological, environmental, and engineering studies.[31]

The CERC extended its Sand Inventory Program to the Southwest in 1977. At the request of the Galveston District, CERC conducted a combination geophysical and coring study to assess the availability of offshore sand along 85 kilometers of the Texas Inner Continental Shelf centered on Galveston and extending about 10 kilometers offshore. The published report (1978) provided information on the general geological character of the region.[32]

In the late 1970s, CERC initiated a more sophisticated version of the Sand Inventory Program: the Inner Continental Shelf Sediment and Structure (ICONS) Program. The field exploration phase of the ICONS Program consisted of continuous seismic reflection profiling supplemented by obtaining cores

of the bottom sediment. Contractors supplied data that the CERC Geology Branch staff analyzed and interpreted. The CERC staff laid out geophysical survey tracklines for study areas in two basic configurations: grid patterns, to cover areas where a more detailed picture of seafloor and subbottom geological conditions was desirable, usually those areas thought to contain sand and gravel; and reconnaissance lines, which consisted of one or more continuous shore-paralleling zigzag lines that provided a means of correlating geology between grid areas. The resulting data revealed the general morphological and geological aspects of the area and identified seafloor areas where more detailed data were needed.[33]

Public Issues and Changes in Corps Programs

In the 1960s, the American people became more concerned about the deterioration of the natural environment. Environmental groups, though operating with modest resources and limited access to decision-makers, became potent forces for change in Federal policies.[34] As the environmental debates drew national attention, they raised three important organizational questions. The first involved what position the Corps should take regarding the environment. A second was how to resolve the clash between the traditional engineering orientation, prominent at the District and Division levels, and the environmentally sensitive attitude emerging within OCE. The third was how to preserve the Corps' traditional decentralization of authority and yet achieve uniformity in this important policy area.

The Corps' top leadership opted for a break with traditional policies. Lieutenant General William Cassidy's June 1969 memorandum to the Assistant Secretary of the Army for Civil Works suggested that the Corps adapt to new national requirements. He recommended expanding the Corps' research, especially for lake and ocean shore protection.[35] In the National Environmental Policy Act of 1969, Congress required the Corps to assess the impact of its projects on the environment. On 2 April 1970, Chief of Engineers Lieutenant General Frederick J. Clarke created an Environmental Advisory Board consisting of six prominent environmentalists and began a process of formally exchanging views with the environmental community. On May 11, Clarke explained the new Corps policies in a letter to the field organizations; he spelled out the procedures the Corps would take to "demonstrate institutional maturity in acting on environmental issues."[36]

In time, the expanding environmental movement led President Jimmy Carter to proclaim 1980 the "Year of the Coast." The coastal zone received attention concerning three issues. The first, relatively noncontroversial, related to the urgent need for more understanding of the natural processes affecting physical changes in the coastal and beach areas, many of which were undergoing a development boom that showed no signs of abating. The second pitted advocates of controlled development against those advocating no development at all. Third, the resulting debate focused on the future of the undeveloped barrier islands. Soon, this third issue began to overshadow other coastal zone questions.[37]

Barrier Islands

Almost one-half of the United States coastline and more than 60 percent of the Atlantic and gulf coasts are composed of barrier island landforms. The 293 barrier islands along the eastern and gulf coasts of the United States stretch in a broken and irregular chain from Maine to Florida and west to Mexico. Barrier complexes can be divided into two main elements: the barrier itself, which may be either a barrier island, barrier spit, or bay-mouth barrier; and the bay, lagoon, or estuary sheltered by the barrier. These elements can in turn be divided into a number of subenvironments with characteristic morphology, sediment distribution, fauna, and sedimentary processes.[38]

Scientists assume three primary origins for the linear, shore-paralleling barriers: the development of spits parallel to the coast that subsequently are dissected by inlets, the submergence of coastal ridges due to a rising sea level, and the buildup of subtidal sand shoals. Barrier islands prevent tidal waves from advancing. Inlets between barrier islands are similar to spillways because they permit water to be forced landward as the tidal wave approaches and crests and then reverses the flow as the tide ebbs. Barrier islands can be separated into distinct groups. Different theories explain the morphological characteristics of each. While barriers vary considerably in shape and relief, most are composed of loosely compacted sandy sediment easily transported by wind and water, thereby leading to erosion or deposition on the islands and in adjacent areas. Barrier islands are inherently unstable and unpredictable.[39]

Public interest focused on understanding the natural processes of how barriers formed and evolved

and the degree to which the islands could be inhabited without causing detriment to nature.

Development of barrier islands was negligible until roads, causeways, and bridges were built to provide vehicle access. By 1973, approximately 14 percent of the barrier island acreage was urban, as compared with 3 percent urbanization of the total lands within the United States.[40] By the 1970s, 70 barriers were highly developed, and approximately 100 more were being developed.[41] Two kinds of public financial support underwrote the development: funds for basic community facilities and aid to protect developed areas. The public subsidy amounted to more than $96.7 million for 3,784 acres or $53,250 per developed barrier island acre.[42]

CERC Barrier Island Programs

Despite an alleged bias toward construction projects, the Corps had shown little interest in work on the 68 unspoiled barrier islands. When the fate of the undeveloped and partially developed barrier islands first emerged as a political issue, in the fall of 1969, CERC conducted two workshops to determine the present state of knowledge and research.[43] Various other studies, mainly data gathering, followed. By 1980, the growing public interest in the future of the barrier islands and the accumulated data led CERC to reorganize its efforts in a broad-based research program designed to address some of the technical and scientific questions about barrier island formation and the natural processes causing their dynamic nature.[44] The CERC researchers were interested in five general topics:

1. Research to identify and quantify sources of sediment that comprise barrier environments. This involved analyses of sediment samples from various islands and adjacent nearshore areas as well as the use of geophysical and side-scan sonar equipment to identify sediment sources, transport paths, and sinks.

2. Research using the results from field investigations that bore deeply into the soil and revealed long cores and from mapping surveys of marsh areas in Virginia and New Jersey. Analysis would lead to a better understanding of the processes and environmental conditions needed to form and maintain biologically productive marshes.

3. Exploring further the three-dimensional sedimentary framework of several Virginia islands that had been determined by careful analysis on long cores. Age dates of organic material in the cores, determined by radiocarbon techniques, yielded clues to large-scale changes in sea level elevation. The core data and historic maps of the Assateague region of Virginia also proved useful in describing how capes could form on previously straight coastlines.

4. Continuing joint research with NOAA's National Ocean Survey, which had produced a series of maps showing changes in coastal morphology for Delaware, Virginia, Maryland, and North Carolina over the past 130 years. This information, combined with cores and profiles from shoreface areas, was also being used to study how the nearshore responded to past rises in mean sea level.

5. For purposes of 50- to 100-year design and for planning, reviews of the literature on long-term sea level changes which, hopefully, would allow researchers to verify and quantify the major local and worldwide factors that affect sea level elevation.[45]

The CERC barrier island work unit developed in the 1980s from the requirements of the Barrier Island Act. One popular idea was that barrier islands rolled

View of Fire Island at Davis Park, New York, 1962

over, that is, migrated by accreting on their land side while eroding on their ocean side. The concept had emerged from studies of the special conditions of the North Carolina barrier islands, which are shorter and have thicker ground cover and fewer inlets than the Virginia barriers.

Each barrier island area presents different problems. The Louisiana barriers are deltaic; they first formed as sandbars and then shaped into barrier islands. As material compacts and subsides, these islands begin to sink. In New Jersey, a sediment deficit exists. Most barrier islands have receding shorelines, which are not always caused by erosion. On the North Carolina coast, which is affected by a progressively rising sea, barrier islands face inundation from both the ocean and land sides. The shape of the land on a barrier island is important. On a flat slope, short-term changes of as little as one-third of a meter are significant because shoreline movement of 60 to 100 feet can affect calculations of the effectiveness of a structure or project maintenance costs.[46]

The Barrier Island Sedimentation Study indicated that with back-bay marshes growing on a variety of substrate materials, sand overwash was not as vital as some researchers had contended; that inner shelf areas feed sand to the coastal littoral budget; and that, according to a study of shoreline change maps covering an historical period of as much as 150 years, barrier islands showed complex changes which were not always due to the works of man. By 1983, a study of approximately 97 miles of North Carolina barrier islands to determine changes over periods ranging from about 75 to 100 years had concluded that most of the barrier islands were eroding on both the ocean and sound sides, but none of the islands seemed to be migrating landward. The results suggested that theories of barrier island rollover could have application in geological, but not historical time.[47]

When CERC moved to Vicksburg, most of the barrier island work group stayed in the Washington area. As the new team was assembled, members reorganized the program to identify particular controversial issues that interested planners in the Districts. Specifically, the work group moved to do more concentrated study of the phenomena of sea level rise, jetty and groin projects, and subsidence. (The last is a significant problem along the gulf coast shoreline where Louisiana loses some 50,000 acres of marsh per year. Causes include land sinking after gas is pumped out, sediment consolidation, and rising seas. Swamp buggies used for oil rig explorations are also a major factor. The buggies cut wide swaths through marshlands, and the resulting channels lead to marshland loss.) The work group also investigated the shorter term fluctuations that increase water along the shore because of atmospheric pressure changes offshore. This resulted from changes in the upper atmosphere winds, the El Nino cycle, and shifts in the warm-water Gulf Stream that cause the denser nearshore cold water to move.[48]

Environmental and Ecological Programs

CERC's ecological research program had its beginnings in the Beach Erosion Board's development of methods to use vegetation to solve coastal engineering problems. Experiments conducted between 1956 and 1976 demonstrated that dune grasses planted on barren sandy areas on the landward side of the beach trapped wind-transported sand to create dunes. In North Carolina, the average annual sand capture rate on planted areas was approximately 5 cubic yards per linear foot of beach. On some stretches of the shore, rates ran as high as 12 cubic yards. In North Carolina and Texas, experimental dunes grew vertically at an average rate of more than a foot a year over a five-year period.

Marsh development was pioneered in the late 1960s under research partly supported by CERC. By 1971, researchers had transformed a barren, dredged-material island in Cape Fear estuary into a productive intertidal marsh. Successful plantings on dredged-material deposits and eroding banks proved to be an effective and low-cost method of stabilization and erosion control. In the Chesapeake Bay, two parts of an eroded island were rejoined through the use of marsh plants.[49]

Using vegetation to control erosion was introduced into the Great Lakes after discussions at a December 1976 workshop disclosed the lack of experimental work. The North Central Division and CERC cooperated with the Michigan Department of Natural Resources and the Pennsylvania Department of Environmental Resources in dune building field tests at Ludington State Park, Michigan, and Presque Isle State Park, Pennsylvania. After the dune system at the latter site was leveled by a 1968 storm, the shoreline receded and formed a narrow beach bordered by a forest. The field test involved planting 250 feet of this beach with American beach grass

Before and After View of Marsh Restoration at Duck, North Carolina

summer drought, the plantings were not as successful.[50]

Two Coastal Technical Aids on vegetative erosion control were published by CERC. CETA 77-3, based on CERC field studies on the Atlantic, gulf, and Pacific coasts, addressed the use of plants for bank stabilization and marsh development; it included information on plant selection, planting techniques, and labor requirements for salt marsh development projects. CETA 77-4, based on more than 15 years of CERC field studies, set forth design criteria for dune creation and stabilization using beach grasses. In 1979, CERC published the Special Report series, the first comprehensive report on coastal marsh creation in the United States. By now, CERC investigations had established that marsh plants were effective in stabilizing eroding banks in many sheltered coastal areas; that techniques were available for the effective propagation of these marsh plants; and that the methodology, applied by various Corps Districts and local agencies and institutions, had produced exceptional results in various environments at a fraction of the cost required for comparable structural protection.[51]

obtained from the Soil Conservation Service. The Ludington site was a part of State Highway 31 that had been relocated due to shore erosion. American beach grass and prairie sand reed were planted along a 1,200-foot section of beach. A survey of the test planting at Presque Isle in October 1977, five months after planting, showed the survival and growth of the American beach grass plants were among the highest ever recorded. At the Ludington State Park demonstration site, which had experienced spring and

Ecology Research Program

A formal ecology research program originated with problems related to the dumping of sewage sludge in the ocean off New York Bight. The highly publicized dumping raised questions about the Corps' permitting authority and procedures. Concerned because the Corps had issued the permits and thus drawn fire from environmentalists, the Chief of Engineers in 1968 instructed CERC to study the question.[52] Hydrographic, geological, chemical,

and biological investigations contracted by CERC estimated circulation patterns, made chemical analyses of the concentrations of a number of elements, analyzed sediment samples, and developed basic data related to the disposal of sewer sludge, dredge spoils, and acid-iron wastes. The research task required hiring the first CERC biologists. The result was a more detailed environmental description of the bight dumping grounds and adjacent areas.[53]

From these beginnings came the CERC ecology program and the Coastal Ecology Branch, formed in FY 1970. The branch, staffed by three professional biologists and one co-op student, examined the environmental effects of all Corps coastal engineering activity. A major part of the program was concerned with the uses of vegetation in coastal engineering and involved studies of dune building and stabilization, marsh building on spoil, and vegetative control of bank erosion on the Atlantic and gulf coasts. The program also studied the effects of coastal engineering activities on ecosystems. Other investigations included studies of the effects of offshore dredging, including the use of dredged material for beach fill, of dredge spoil deposition, and of the effects of suspended and deposited sediments on estuary organisms.[54]

When CERC completed its Field Research Facility, the Coastal Ecology Branch established an environmental measurements program to measure and record data on meteorological and oceanographic conditions. The CERC tested the use of native marsh vegetation to abate erosion of the eroding shoreline. The experiment, carried out with four plant species, was successful; the erosion rate slowed, and many new plant and animal species invaded the new marsh habitat. In 1980, observations showed that experimental marsh plantings established between April and September 1973 had stabilized the sound-side shore of CERC's Field Research Facility, which had been eroding at a rate of approximately five feet per year.[55]

In related experiments, CERC conducted research to obtain quantitative information on the ecological effects of constructing rubble-mound coastal structures such as groins, jetties, breakwaters, and islands.[56] The CERC also experimented with marsh development using dredged material (called "spoil" until 1979, when the name was replaced by the less offensive term) that was produced in great quantities to maintain navigation channels within sounds and estuaries. This work originated from two imperatives. Beginning in the 1950s, the number of acceptable landfill disposal sites had dwindled, making the disposal of dredge spoil material a major problem. The Waterways Experiment Station established a research program to develop, test, and evaluate the use of material in marsh development. The WES surveys identified environmental benefits. The CERC found that Corps-built rubble-mound structures, used in breakwaters, were ideal artificial reefs. Because they were built of natural stone with various cracks and crevices exposed to the entire water column, such structures attracted a great diversity of reef dwellers.[57]

Offshore Construction

Ninety percent of all marine construction takes place in water less than 50 meters deep. Early on, CERC began to summarize laboratory and field studies in the United States to better understand the interaction of the beach and the littoral zones with and without man-made structures. In 1976, CERC began to reorient its research program toward better Corps Division and District support for dealing with geotechnical engineering problems.[58]

The CERC's Offshore Engineering Program consisted of four types of work. One set of studies assisted engineers in designing structures. An example was the Sub-Ocean Soil Mechanics Study. Its objectives were to determine what knowledge was available on ocean floor soil mechanics and to identify the most-needed areas of study relating to subsurface exploration; in situ testing; and construction activities such as excavating, fill, and structural foundations. This research also focused on developing equipment and procedures to meet the needs defined by the material survey. After accumulating sufficient data on engineering characteristics of ocean floors, researchers examined and tested the applicability of existing soil mechanics design techniques and procedures for engineering projects on the ocean floor. The program also resulted in the publication of "State-of-the-Art and Marine Soil Mechanics and Foundation Engineering."[59]

The second part of CERC's Offshore Engineering Program consisted of laboratory studies to gain basic insight into the physics of coastal construction. Coastal structures subject to high breaking waves cannot be built of stone when the waves exceed 30 feet. Common engineering practice was to use variously shaped concrete blocks, which were relatively more stable than stone. When a review of

published stability coefficients for the armor units indicated that the dolos shape (developed in South Africa and tested at the Waterways Experiment Station) yielded the most stable structure, CERC formulated a design that was subject to hydraulic tests. Other search led to the publication in 1978 of a study of the effects of wave forces on submerged pipelines. The study results allowed designers to evaluate the alternative of emplacement without a trench. Other studies related to construction in relatively deep water and the effect of large nearshore structures on waves hitting adjacent beaches.[60]

As the third element of the program, CERC undertook field studies to verify the results of the laboratory studies and to acquire additional information. Investigators listed offshore structures, including locations and basic construction details, the design conditions under which each was built, and the general purposes the structures served. Researchers studied breakwater performance, including that of a floating breakwater, and wave forces assaulting pipelines near the bottom. Laboratory researchers tested elements of the four- and six-unit-wide Goodyear Modular Floating Tire Breakwater in the CERC large wave tank.[61]

Finally, CERC evaluated projects for their economical and ecological feasibility. The Rincon Island Study was the most elaborate. Located approximately one-half mile offshore in the Santa Barbara Channel of California, the 2.1-acre island was built in 1959 in 45 feet of water to develop a 1,200-acre offshore oil lease. After the island was built, the Atlantic Richfield Company decided to construct a steel-pile causeway. CERC contracted to determine whether the island was meeting its intended purposes: the effectiveness of the construction methods; the effects of the structure on the physical environment, waves, sediments moving along the beach, and sediments in the vicinity of the island; and the effects on the ecology of the area. The west side of the island was protected by approximately 1,300 31-ton tetrapods. Designed for 27-foot-high waves, the tetrapods had withstood 20-foot waves and remained stable for 14 years. Study revealed that three different marine environments had been created in the island's vicinity with differing types of marine life. Prior to the island's construction, marine life was estimated at 25 to 30 species, of with 14 species had been identified. After construction, 298 species of marine life were identified and probably more were present.[62]

Use of Dolos for Construction at Crescent City, California, 1986

Hurricane Flooding

Long responsible for maintaining and improving ship channels into coastal harbors, by 1963 the Corps of Engineers also was charged with protecting shores and beaches from erosion and preventing the flooding of coastal areas by hurricanes and tsunamis. The increasing use of shore areas and nearshore waters for recreation gave new impetus to the building of small craft harbors with suitable access channels and to the restoration and widening of eroded beaches. To accomplish these tasks, the Beach Erosion Board, heretofore concerned with problems of land-sea interaction, also had focused on the air-sea interaction (wave and storm surge generation) and air-land interaction (beach decrease and dune building and stabilization).[63]

By the mid-1970s, the Corps had several new reasons to calculate sea level reactions to hurricanes. The Federal Insurance Administration, which had to set insurance rates in coastal areas, turned to the Corps for estimates of the probability of flooding in hurricane-prone regions. The Nuclear Regulatory Agency needed similar estimates to ensure proper safeguards for licensing nuclear power plants. General construction projects had to be planned with the knowledge of flood damage probability due to storms. Being able to predict surge heights also

would provide better emergency warnings for which NOAA's National Weather Service was responsible.[64]

The Storm Surge Work Unit in CERC's Oceanography Branch used various numerical models to determine the anomaly from mean sea level due to tides and severe storms. (Numerical models had to be employed because physical models constructed in laboratories had been unsatisfactory; simulating hurricane wind fields was not possible.) The most common numerical model was the finite-difference model, of which there were two types. One predicted surges for large, open coastal regions. The other was limited to smaller scale and in-shore regions. Each model had strengths and weaknesses.

The Storm Surge Work Unit's aim was to use both the open-coast and in-shore models to examine coastal effects and details by area. The open-coast models used by NOAA and the WES allowed a coastline to be represented as a curvilinear boundary rather than a straight line and could predict the water level at the coast, but they could not predict flooding. A model developed for the Flood Insurance Administration by Tetra Tech of California, known as the Tetra Tech model, allowed flooding of the coast by removing the vertical wall between land and water. The WES in-shore model predicted the water level in an inlet region but failed to show the effect on local rivers. One CERC model predicted water level for an in-shore region and showed the effect of river transport.[65]

By 1976, CERC had produced a model that incorporated the output results of the NOAA model (SPLASH II) to supply boundary conditions for the CERC inshore model. The Office of Chief of Engineers directed WES and CERC to run three open-coast models (NOAA SPLASH, Tetra Tech, and CERC's S-SURGE III) and three inland models (SURGE, Tetra Tech, and the WES Implicit Flooding Model, WIFM). The Office of the Chief of Engineers also directed the Committee on Tidal Hydraulics to evaluate the results either to select a model for uniform use within the Corps or to determine if research were needed and, if so, what type.[66]

The research findings were inconclusive. While the hydrodynamic models were developed adequately, the meteorological input was not, and both the calibration and verification bases were lacking. Also, the different hurricane models did not agree. A major problem was that the application of the Federal Insurance Administration model proved so difficult for developers and others in politically significant communities that Congress had backed away from taking a stand. In fact, some congressmen had found their reelection threatened because they had supported the rigid application of professional knowledge to the economic development of the coast.[67]

For several years, as part of a research project for predicting storm erosion, CERC field crews sought to anticipate major coastal storm activity early enough to survey a particular beach just before and after a storm occurred. On 9 August 1976, Hurricane Belle raged up the east coast, forcing vacationers to evacuate beach resorts from North Carolina to Rhode island. The CERC employees went to Ludlam Island, New Jersey, to monitor the storm's effect. The storm arrived two hours later with torrential rains and a spring high tide. At peak intensity the storm was 25 miles east of Atlantic City with sustained winds of 100 miles per hour near its center. Researchers surveyed the beach along Ludlam Island after the storm had passed; conducted poststorm inspection trips to North Carolina and Long Island, New York; and contracted poststorm beach surveys at Virginia Beach, Virginia, and in Dare County, North Carolina. Similarly, following the damaging coastal storms along the east coast in the winter of 1977-1978, CERC survey teams visited sites in New Jersey and North Carolina.[68]

Summary

The Coast Engineering Research Center's research programs, with their field and laboratory testing and data collection, had immense practical value. Before beach nourishment could be used widely, offshore sand deposits had to be located and simple, economic methods of transporting the material had to be devised. The Sand Inventory Program found plentiful supplies of sand deposits necessary for beach nourishment and pioneered new transport methods. The sophisticated ICONS Research Program also detected sand deposits for use in shoreline nourishment and improved understanding of geological and hydrological processes.

Engineers had long used groins, jetties, and breakwaters. The seemingly proven qualities of these structures obscured the fact that most engineering involved was rule-of-thumb. The Coastal Engineering Research Center pioneered field studies to determine how groins behaved under various

Sand Fencing at Padre Island, Texas, 1971

the site selection and design review of projects under the panel's auspices.

The Corps' long-term disinclination to participate in projects promoting the development of unspoiled barrier islands dated back to the days of the Beach Erosion Board. When environmental issues emerged, CERC research laid a firm base for the Corps' responses. The Barrier Island Sedimentation Study tempered the emotional debates by providing more precise data about the types of barriers and the changes they were undergoing. The Ecological Research Program, which was created to find ways to deal with the problem of sewage dumping, pioneered in developing ways to use vegetation to solve coastal engineering problems and in techniques of marsh development. Beginning in 1970, an expanded CERC Ecology Program looked at the environmental effects of all Corps coastal engineering activity. In other areas, CERC field and laboratory research made significant contributions in the areas of offshore engineering and construction and in anticipating the effects of hurricane storm surges. A practical application of the latter work has been the use of CERC poststorm beach surveys to estimate disaster relief funds in the wake of hurricanes.

shore conditions; conducted field and laboratory tests of various types of offshore breakwaters, providing guidelines for their use; and was at the forefront of weir jetty design and research that combined the jetty and sand bypassing in one system.

The Coastal Engineering Research Center represented the Corps in major national studies. The Center provided much of the manpower and expertise for assembling and evaluating data from the National Shoreline Study, the first detailed inventory of the Nation's coasts. Congress's establishment of the Shoreline Erosion Advisory Panel was based on prior CERC studies, and CERC played a key role in

V

ORGANIZATIONAL CHANGE AND COASTAL ZONE RESEARCH

When President John F. Kennedy took office in 1961, the Corps prepared for a period of increased public works construction. Asked to formulate a public works program that addressed the needs stressed in Kennedy's campaign, the Corps estimated that by the mid-1980s the United States would require new construction projects with first costs totaling $28.2 billion.[1] The actual programs were less extensive, but still Corps budgets rose rapidly. Between 1952 and 1958, annual appropriations for Corps civil works activities had averaged $551.6 million annually. Congress appropriated for the Corps $975.1 million in 1962; $1,046.4 million in 1963; $1,096.7 million in 1964; and $1,167.2 million in 1965.[2] The Coastal Engineering Research Center benefited from the New Frontier philosophy characterized by growth and optimism.

Reorganization of the Corps Planning Process

The Corps was not considered a good planning agency. Staff in the offices of the Secretary of the Army and the Bureau of the Budget often despaired of getting the Corps to broaden its base of expertise and look beyond project construction. Some doubted the Corps' capability to carry out a unified and integrated national water resources policy. A 1962 internal Corps study recommended that the Secretary of the Army appoint an advisory council to assist him with the civil works program, a response to frequent criticism that the Corps had a narrow and strictly engineering approach to the development of natural resources. In 1964, Army Secretary Cyrus R. Vance appointed a Civil Works Study Board to make specific recommendations for Corps changes.[3]

At the Bureau of the Budget, interest in the Corps focused on coordinating the construction programs agencies and reviewing and appraising these projects using comprehensive planning techniques. The Bureau's position was that although the Corps had initiated some reforms, the organizational response was too slow.[4] As a bureau memorandum written in 1965 put it,

> . . . in general, the [Corps'] planning process is still dominated by the engineering profession, and is often very narrow in concept and unimaginative in execution . . . it will not improve greatly unless a *major* effort is made to diversify and strengthen the planning staff and pull it out of the engineering (construction dominated) organization.[5]

In January 1965, Secretary Vance's Civil Works Study Board completed its work, and Congress in February 1966 published a report criticizing the Corps for "current policies, procedures, organization and staffing" that failed "to deal effectively with a much changed and continuously changing water resources environment." Legislation introduced in Congress in 1965 called for creating a new department of natural resources that would absorb the Corps' civil works functions.[6] This was the seventh attempt since World War I to shift civil works to the Department of the Interior or its equivalent. In a letter to Senator Frank E. Moss, Chief of Engineers William F. Cassidy responded that the country did not need a new agency, but that executive agencies needed to apply the modern principles of organization and administrative management to their operations.[7]

Cassidy was referring to business management concepts designed to prepare organizations for the long term. The most popular ideas were the Planning-Programming-Budgeting System (PPBS) and systems analysis, which Secretary of Defense Robert McNamara had introduced into the Department of Defense budgeting process to integrate long-range planning with fiscal year budget requests.[8] On 12 October 1965, the Bureau of the Budget notified the heads of executive departments and agencies that an

integrated PPBS would be adopted to improve the program review process.[9] The bureau assumed that the most effective policy choice could be identified by estimating quantitatively the factors involved in alternative courses of action.

At OCE, staff members considered ways to upgrade the Corps' planning capabilities. The best of the proposals called for establishing in each Division and District office a civil works planning division comparable to that in OCE. The planning divisions would be headed by the most able individuals the Corps could obtain, who would hold General Schedule grades equal to the chiefs of the engineering divisions, traditionally the most prestigious and powerful positions in the Corps.[10]

The Planning-Programming-Budgeting System was introduced into the Corps on 22 March 1966.[11] In July, a Policy and Analysis Division was established in OCE's Directorate of Civil Works. Designed to formulate and disseminate policies governing the civil works program, the new division provided the Chief of Engineers with the staff required to reinforce policymaking.[12]

The division was organized under the direction of B. Joseph Tofani, a professional engineer. He had begun work in the water resources field in 1935 with the Bureau of Reclamation; served with the Soil Conservation Service, the Corps, and the Commonwealth of Pennsylvania; and, after returning to the Corps in 1942, had moved up through the organization to become, in 1966, the chief civilian advisor to the Chief of Engineers. Tofani felt the Corps needed to make broad, basic changes in its operation. Establishment of the Policy and Analysis Division substantially expanded his capacity to influence policy to this end. With the backing of successive chiefs, Tofani reorganized the Office of Chief of Engineers. Instead of the various civil works divisions reporting to the executive officers, with engineering the primary division, the Policy and Analysis Division was involved in most substantive decisions.[13] The Policy and Analysis Division applied the PPBS to all civil works activities. Under earlier planning procedures, Corps field offices made up their own strategic plans, which then were fitted together as they progressed up the organizational chain. Under PPBS, the planning environment was organized into mission areas. Each Corps research group was directed to develop a Research Program Memorandum. Designed as a practicable way to present information about research activities and to give reviewers a rational basis for making sound decisions on the total research program, including appropriate trade-offs among various subprograms, the Program Memorandums required laboratories to justify their activities in dollar terms.[14]

Emphasis on this type of careful budget planning intensified after Assistant Secretary of the Army for Research and Development Robert Johnson visited various Army Research and Development (R&D) laboratories in 1971. Believing that better planning would help the Army laboratories meet future Army needs, he initiated publication of an Army Regulation that recommended additional planning guidelines. On 1 November 1972, the Office of Chief of Engineers, by establishing a Civil Works R&D Board to provide policy guidance, review programs, and oversee and evaluate projects, imposed PPBS on the research laboratories.[15]


Seawall at Ventura, California, 1972

Research and Development Office

The next step was the establishment of a research and development office for the Corps. Traditionally, OCE had administered two distinct yet complementary programs: the comprehensive civil works water resources development and multi-faceted construction supporting national military objectives. Research was conducted primarily at five engineer R&D centers: the Construction Engineering Research Laboratory at Champaign, Illinois; the Cold Regions Research and Engineering Laboratory at Hanover, New Hampshire; the Waterways Experiment Station at Vicksburg, Mississippi; and the Coastal Engineering Research Center and the Engineer Topographic Laboratory, both at Fort Belvoir. Some additional research and development work was performed by the Institute for Water Resources at Fort Belvoir; by the Hydrologic Engineering Center at Davis, California; and by the Facilities Engineering Support Agency at Fort Belvoir. In 1976, the Corps laboratories were staffed by approximately 2,400 scientists, engineers, and support personnel and operated with a combined annual budget of more than $75 million. An additional $13 million in Corps research funds was budgeted to support the Army Environmental Scientists Research and Technology Program at five Army laboratories.[16]

The Hydrologic Engineering Center, CERC, WES, and the Institute for Water Resources reported to the Director of Civil Works, who, in his operations and engineering branch, had an assistant director for research and training and about 12 program or technical monitors who oversaw the work of these four entities. The military Construction Engineering and Operations Division had 30 to 35 technical monitors and a small staff called the Office of Planned Research and Systems. In addition, the Director of Military Engineering and Topography had a Resource and Development Division that monitored the Engineer Topographic Laboratory. There were, then, eight subunits reporting to three directors.[17]

When Chief of Engineers Lieutenant General William C. Gribble moved to the Corps from the Army Research and Development Office in 1973, he quickly became concerned about the overall Corps R&D program. He felt that while every element of the program was technically sound, including the work of the laboratories, the components needed to be combined in a cohesive program. Gribble soon replaced the R&D Board with a Research and Development Review Board, made up of at least three directors plus the Deputy Chief of Engineers for Civil Works, who chaired it. The board activities were reviewed by a designated Corps chief scientific advisor, who (with no staff) was briefed by various elements of the Corps.

In the late summer of 1973, Gribble asked William Taylor to join his staff to plan an improved R&D program that would oversee both the military and civil works R&D activities. Gribble's guidance to Taylor was to concentrate on the role of the user, "the guy who has the problem which needs to be solved." At the time, civil works R&D totaled some $15 million yearly, excluding reimbursable work, approximately 1 percent of the total civil works program. The military R&D work amounted to $15 to $20 million a year, approximately 1 percent of the Army's research, development, technical, and engineering program.[18]

Gribble's proposal took shape in a research program that called on the Districts and Divisions to define operational problems. These then would be grouped into fields of research activity. The eight Corps research units would propose programs to the program office of the Deputy Chief of Engineers. The Research and Development Review Board would recommend the total research program. Problem-solving research would have top priority. To speed up results, laboratory directors would be given increased authority and considerable latitude, but the laboratory efforts would be reviewed and, if necessary, redirected. The technical work would be continuously monitored, and all programs would be reviewed periodically. Researchers would strive to see that their results were communicated in a form users could employ. Taylor told the CERB in 1974 that the new system would solve the problem whereby the laboratories would do excellent research but produce a technical report that the Division or District engineers could not use because they lacked the time to translate the research into engineering specifications.[19]

The more intensive focus on applied research differed significantly from the CERC philosophy. Personnel in CERC agreed that all Corps laboratories, including CERC, had an applied basic research mission. The Center, however, defined "Basic Research" as that "directed toward obtaining an understanding of some phenomenon without concern for its eventual usefulness in solving real problems" while "Applied Research" was that "directed toward obtaining an understanding of some

phenomenon with the application of that knowledge to the solution of a real problem." The Center then concluded that all of its research "must be considered applied." Within its own organizational frame of reference, CERC defined its output as "direct applied research," meaning research resulting in information that could be applied to problems faced by the Corps' field offices immediately; "supporting applied research," research not appropriate for direct application; "technology transfer," which put research findings into design criteria or provided data analyses for solving of field problems; and "data collection," which was research for field use in planning and design.[20]

Now CERC asked for and received an exemption from the regulations governing the preparation of budget requests as applied to other Army laboratories. Unlike the other laboratories, CERC sent OCE a list of its goals and objectives attached to a cover letter updating the CERC ten-year plan that OCE had adopted in 1965. Acting CERC Technical Director Thorndike Saville, Jr., appended a notation that OCE had determined that the particular Army Regulations did not apply specifically to CERC.[21] This opinion was shared generally by the CERB. When briefed on a proposed Engineer Regulation, for example, a CERB subcommittee requested special interpretations for CERC. At a 1974 meeting, CERB members commented that because the Districts and Divisions could not possibly respond to all the various future problems, a group like CERC had to concentrate on the Corps' broader research needs.[22]

While CERC was proceeding internally to define research, a Research and Development Office (RDO) emerged as a directorate on the OCE staff with command and control over the laboratories and a bias toward military-oriented problem solving. The impetus to create the RDO had come from the military side of the Corps, and the office had been organized by a military engineering study group. Both military and civil works functions were created within the RDO, but none of the high-level technical personnel came from the civil side. The larger and more important military program now began to push the Corps laboratories more into applied research.[23]

Over the next decade, clear-cut procedures evolved. Under the Directorate of Research and Development (DORD), successor to the RDO, programs were organized into seven research areas. After a need was identified, the technical monitors set priorities, and DORD directed the Corps laboratories to develop programs to respond to them. Each program went through repeated reviews. Chaired by DORD, these involved Headquarters, laboratory personnel, and the District and Division users.

Out of the reviews came changes, refinements, and adjusted priorities. The Directorate of Research and Development then submitted the packaged review program as a recommendation to the Civil Works Research and Development (CWRD) Review Committee. Chaired by the Deputy Director of Civil Works, the committee was the real decision-making body for the civil works portion of the Corps budget. Members included Division chiefs in the Civil Works Directorate and from the Engineer and Construction Directorate. From the CWRD Review Committee, the amended research package went to a Research and Development Review Committee for an information briefing, to the Deputy Chief of Engineers, and then into the budget review process defined by the Office of Management and Budget.

Once the Corps' research and development budget was approved, DORD monitored it, keeping track of the researchers and programs to ensure that operations remained within budget. Major questions were decided within DORD, which saw itself as a service organization to the Corps charged with ensuring that research met a valid need in the civil works and military programs. Many DORD accomplishments were much needed: DORD improved the checks and balances in the existing system, made sure that Corps procedures were followed, standardized budgeting and accounting procedures, established justifications for research, required new reports to enhance the Corps' image, and instituted five-year programs incorporating principles of management to upgrade laboratory performance.[24]

Coastal Engineering at the Waterways Experiment Station

As described previously, the Waterways Experiment Station had been directed to limit its general investigations of tidal inlets to basic research. Denied the right to use the facilities funded by CERC, for site-specific model studies, the WES Wave Dynamics Division shrank to a small group that carried out mostly traditional, technical studies of breakwaters and small-boat harbors. In 1969, a CERB subcommittee pointed WES in a new direction when it recommended that a ten-year schedule for the model inlet studies program be compressed to five.

The subcommittee moreover reminded WES that the Bureau of the Budget wanted the Corps to upgrade its general investigations and research methodologies and that new inlet investigations should begin using mathematical models.[25]

In 1971, Robert W. Whalin became the Chief of the Wave Dynamics Division (WDD) of the Hydraulics Laboratory. With a B.S. degree in physics from the University of Kentucky, an M.S. degree in physics from the University of Illinois, and a Ph.D. in physical oceanography from Texas A&M University, Whalin was a registered professional engineer with a large number of technical reports and papers to his credit. More important to the immediate future at the WDD, he also was familiar with the mathematical modeling techniques that were gaining more attention in the field.

In 1971, WDD was handling laboratory, numerical, and field investigations concerning coastal and ocean engineering aspects of Corps project studies. In January 1974, the WDD took over investigation of tidal inlets research and project-related studies. The change, part of a general reorganization that reduced the number of WES laboratories from six to four and the number of divisions in the Hydraulics Laboratory from six to five, centralized all coastal and tidal inlet-related work at WES in one division, an outcome Whalin favored.[26]

Robert W. Whalin

Whalin had one ambition, a plan to achieve it, and three problems, two of which were major and one more soluble. His ambition, simply, was to make the WDD the best organization of its kind: a leader in the field with worldwide recognition for its work. The WDD could use its site-specific work to do basic research while also addressing specific Corps concerns. The Division faced two challenges. To become the acknowledged leader in the field, it needed to recruit experts in applying numerical modeling techniques and to convince the WES Director to acquire expensive, high-quality, unique facilities. A less difficult problem was funding. The WDD had a backlog of experimental technical studies and testing projects and was ensured a steady flow of work from Corps Districts as long as it produced results within the estimated time and budgets.[27]

Construction and operation of the Los Angeles-Long Beach model in 1972 enabled the WDD to emerge at the cutting edge of experimental, numerical, and field measurement technology. Because of the model's large size, it required the automation of all laboratory data acquisition and precise control of the wave generators. The wave generators, designed and procured for the model in 1974, were the first at WES capable of generating a unidirectional wave spectrum. The significance was that the WDD now could study laboratory waves more complicated than those generated from a single source, waves more like those affecting Corps projects.

At that time, the wave generators in use around the world were, like those at WES and CERC, monochromatic. They came in several types, but all were based on the same principle. In some, a paddle pushed water forward to create a wave; in others a lever hinged at the bottom or a plunger initiated wave action. A simple mechanical arrangement produced a series of identical waves of the desired height and period. A monochromatic generator could not duplicate the action of waves of varying heights and periods, however.[28]

Whalin was convinced that to be on the forefront of research, the WDD required a directional, spectral wave generator in addition to unidirectional spectral generators for all wave tanks and model basins. No directional spectral generators existed anywhere, although a $25 million facility was under construction in Norway and plans were under way in England to build a special purpose facility to study wave problems affecting offshore oil platforms. In the planned spectral wave generator, a variable signal could be

Wave Tests at Fish Harbor Model, U.S. Army Engineer Waterways Experiment Station

in the politically sensitive process described in the following section, finally succeeded.[30]

Great Lakes Study

During the early stages of this planning, Whalin was conferring with the North Central Division (NCD) about what was threatening to become an extraordinarily expensive construction project on the Great Lakes. For years, the Corps had kept harbors open by dredging and disposing of the dredged material in open lakes. In 1970, the Environmental Protection Agency indicated that the Corps' continued dumping would contaminate the drinking water supply. This meant dredged material would have to be contained in diked areas.

By 1974, the NCD was looking at a disposal program that contemplated the design of some 41 dredged-material disposal sites. They would be constructed out in the lake, on the shore, or in the lee of a breakwater and as close as possible to the navigation channels and harbors being dredged. The disposal sites had to be sturdy enough to withstand storm-induced wave damage. The construction program was estimated to cost approximately $500 million.[31] Usually, the Division contracted for individual studies to calculate the wave action at each site. Because a site survey could cost from $5,000 to $20,000, the total cost for field studies of material disposal sites threatened to exceed a $500,000.[32]

Only two ways existed to acquire adequate wave data. One was to collect it in the field from wave gages at numerous sites over a long period of time. This had disadvantages. A network of wave gages could provide reliable information, but only after many years and considerable construction expense. Broken or stolen instruments and human error also hampered field data collection. The other technique was to hindcast. As described earlier, this was the technique of using a numerical model and chronological data to construct a past wave climate and thus a statistical base to predict future wave activity. The

sent from a computer to the wave board to create waves which would differ in height and period. A long-term plan to upgrade all WDD monochromatic generators to spectral generators was adopted in 1975 and implemented as rapidly as funding allowed. In 1979, the WDD procured a unique spectral wave generator, which permitted totally independent control of both the piston and the flap (hinged-type, motion), and installed it in a newly constructed wave tank. Acquiring this one-of-a-kind facility gave the Division considerable flexibility in conducting experiments.[29]

Finding a way to alter wave directions was the next step to more closely replicate conditions found in nature. This required a row of spectral generators, each capable of imparting a variable signal to its own paddle, with the paddles linked together with hinges. Whalin eventually would submit plans and a request to WES to construct a new test basin with a directional spectral generator specially designed at the WDD. It would have four sections, each 22-1/2 feet long and each with 15 paddles. Including a building to shelter it, the facility would cost approximately $2.5 million. When a cost analysis showed that WDD could return from reimbursable work the money borrowed from the Corps' revolving fund, and after approval by WES Headquarters, the request was inserted as an item in the WES Five-Year Plan. In 1978, WES began to seek OCE approval of the acquisition, and,

Coastal Engineering Research Center used a model developed at the National Weather Service's Technical Development Laboratory. Completely automated and fully operational, this wave forecasting model used estimates of wind speed, fetch, and duration to hindcast wave conditions at 64 points on the Great Lakes. However, because it consistently made high estimates of waves, the model needed to be refined.[33]

Serious problems resulted from poorly designed disposal sites. Problems that plagued Saginaw Bay dredged material facilities in 1976 and 1978 (they had been constructed to the standards in the CERC *Shore Protection Manual*) demonstrate the difficulties. Intended to contain some ten million cubic yards of dredged material, the Saginaw Bay facility consisted of a perimeter dike of 14,000 feet and a crossdike 4,000 feet long. Several design miscalculations later proved to be critical. One was the design still-water level of 580.52 feet, which was derived from gage readings that gave a ten-year Lake Huron and Saginaw Bay design reading. Others were the maximum fetch length of 62.9 miles out of the northeast; the design wave height of 5.7 feet, which was calculated from using a sustained wind of 45 miles an hour; and an anticipated wave runup on the dike structure of plus 11 feet, which was calculated from the rule-of-thumb ratio of about one to one between the design wave and runup (i.e., if there were a design wave of about 5 feet, then the expected runup was, on the average, about 5 or 6 feet).

In 1978, a storm whose characteristics were within the design parameters washed out 1,000 feet of dike at the open end of Saginaw Bay facing Lake Huron. In May 1979, another storm, a little more severe but within the design calculations, came out of the northeast. Again, the runup was greater than expected. This time 3,000 feet of dike washed away. Investigations uncovered three problems. One was the formula specified in the *Shore Protection Manual* for calculating runup, which was far less than what was occurring in the field. The second was that the wave climate in Saginaw Bay was very irregular. This caused engineers to wonder whether the laboratory tests were replicating the actual conditions. The third was the fact that fetch calculations were much greater than originally estimated; they ran all 120 miles to Canada rather than the calculated 62.9 miles.[34]

Contemplating the expenditure of more than $500,000 to obtain the wave data critical to designing the dredged-material dikes at a large number of sites, NCD personnel wondered if it would be possible to design a numerical model that could provide information about wave action at any point on the Great Lakes shoreline. They asked the CERC for an opinion.[35] Pointing to data in the *Shore Protection Manual*, CERC replied that designing such a numerical model was beyond the state of the art.

Whalin had reached a different conclusion. In the spring of 1974, with the possibility of a major study of the Great Lakes in mind, he recruited Donald T. Resio and C. Linwood Vincent, two recent Ph.D. graduates from the University of Virginia experienced in numerical wave modeling. After they had been at WES for a while, Whalin asked them if one could construct a hindcast model of the Great Lakes. "Of course," they replied. Resio, who had used a hindcast model in his doctoral dissertation, saw no problems from the effects of geographical physical outcroppings, and no catabacic effects (different air mass densities) or baroclinic (weather front) effects to consider. Because wave action on the Great Lakes was overwhelmingly generated by the winds over the lakes, in Resio's opinion the project's success involved predicting the winds over the lakes and constructing a wave model that would work in an irregular shoreline geometry.[36]

By July, WES and NCD had worked out the details of what would become the Great Lakes Wave Information Study. The Division authorized the expenditure of more than $500,000 for a three-year project to construct and operate a numerical model to use wind data and to generate a series of numerical simulations that would quantify the wave climate within fairly narrow parameters. If the model worked, the cost was a bargain. The NCD was investing only one-tenth of 1 percent of the construction costs in a study that, if successful, would recoup the initial investment many times over. Resio and Vincent felt they could produce the model. They also liked the challenge. Whalin was certain that even if the larger goal of constructing a fully operational model were not attained, the WDD would be able to deliver a technically adequate product to the NCD.[37]

To construct and operate their model, Resio and Vincent proposed to take 69 years of historical data of the wind fields over the Great Lakes and apply a numerical wave model to estimate wave heights. Factors involved in the model included the coupling between the atmospheric boundary layer and the

waves generated by wind motion, the interaction between waves and the lake bottom, and interaction among spectral wave components.[38] The CERB was impressed and enthusiastic about the plans and techniques.[39] A year was required to construct the numerical model and get it working; computer facilities capable of handling the large data banks were available only at the Los Alamos Scientific Laboratory and there only on weekends.[40] For two years, Resio and Vincent worked more than a full week at Vicksburg and then commuted to Los Alamos to gain access to a Control Data Corporation 6-7600 Computer. They often pursued their research through an entire weekend with little or no sleep.[41]

Because of the lack of continuous wind observations over the Great Lakes, Resio and Vincent had to estimate winds over a lake from such sources as pressure and wind observations at adjacent land stations and from synoptic weather maps. From these sources, sufficient historical data existed only for the wind observations around a lake. Eventually, Resio and Vincent established theoretical relationships between winds over land and winds over a lake and between lake winds and lake waves.[42]

Two approaches were available for verifying the model. The first required a detailed field study on one or more of the Great Lakes involving the collection of wind, air and sea surface temperature, and wave data. This would be costly and could be performed only within a narrow range of environmental conditions. Verification testing thus employed a second approach, a double blind experiment between model hindcasts at WES and wave gage records gathered by CERC for Lakes Erie and Michigan. The Resio-Vincent model hindcasted wave estimates that then were compared with actual wave gage records.

Three sets of data were used. The Center sent Resio and his team the wind information from surrounding airport stations. The team applied the data to the wind transformation model to arrive at a wind field over the lake. Those data were fed into the wave generation model to calculate the lake waves. Results were mailed to CERC, which compared them with the measured CERC data that Resio's group did not.[43] The model achieved a reliability on the diverse geometries of the two lakes better than the hoped-for model reliability of between 1.5 and 2.0 feet for wave heights.[44] The actual error was 1 foot, a close fit between the model and real world data. Between January 1976 and June 1978, the results of the Great Lakes Wave Information Study were published in five reports. Each presented a synthesis of three phases of wave hindcasting for one of the lakes and included the estimation of winds over the water, a picture of the model's operation, and the calculation of wave return periods from program outputs.[45]

The highly successful Great Lakes Wave Information Study established the WDD as a leader in the research field of wave climatology. Resio and Vincent had demonstrated that numerical models of wind-driven circulation, surge levels during storms, and wind-generated surface waves on the Great Lakes produced realistic results when reliable wind data were available. Despite some prior criticism that the land-wind transformation method Resio and Vincent had employed was unreliable, they had demonstrated theoretical justification for the technique and the existence of ample empirical information to evaluate the relationships required in the transformations.[46]

Their success now led researchers to conclude that the hindcasting technique could be employed for the Atlantic and Pacific Oceans and the Gulf of Mexico. With good wind and wave models and appropriate statistical and retrieval techniques, Resio and Vincent believed they could extend their work to all the Nation's seashores. The Corps' South Atlantic Division (SAD), with whom Whalin had been holding discussions, was ready to put up $100,000 to start an initial study.[47] The WDD now was ready to calculate the directional wave climate for all the coasts. It also was centrally involved in CERC's prime research area.

Ocean Wave Information Study

Some at CERC contended that because the Center directed the Corps' coastal engineering research, Corps Divisions and Districts should refer research requests to CERC. The Center proposed to do the projected WES-SAD ocean wave study by deriving the wave climate for the near coastal zone from data on the wave climate in deep water. The data would be obtained by using a deepwater hindcast climatology model developed by the Navy. Selection of this technical instrument rested on the popular assumption that any wave model would provide reasonable answers when properly applied; deviations between measured waves and predicted waves could be explained by discrepancies between actual and estimated wind fields.[48]

Resio's doctoral dissertation at the University of Virginia had employed a Navy-type hindcast model, and Vincent and he had tried to use it in the Great Lakes study. They had found that not only did the Navy-type model not work, but it could be made operational only through radical upgrading.[49] In short, Resio and Vincent had found that the common assumption about models was incorrect. Even if the wind field were specified, Resio said (at a conference called to resolve disagreements between CERC and WDD researchers) different models would deviate significantly in predicting waves.[50] The Navy's model was unreliable, he continued, and because reliable shallow-water data depended on accurate information on deep water, the Navy model should be verified before using it in the type of coastal study CERC planned.[51] Later, Resio would publish a study showing why the Navy model would not work.[52]

Further meetings between CERC and WDD personnel neither resolved the differences nor changed Resio's stand. His position, firmly backed in WDD and by WES, was communicated to OCE as an objection to the proposal that CERC conduct the offshore study. The outcome was a decision allowing the WDD to conduct the Ocean Wave Information Study for the SAD, which funded it the first year. The second year the costs were paid by OCE, which coordinated research efforts with NOAA, the Navy, and others.[53]

Because it is difficult to predict from what area the Corps will need its wave information and precisely what information will be required, the first task was to develop a model containing climatology data for unknown areas. The research team had to find suitable wind data and analyze it to determine the wind field over the entire North Atlantic Ocean. Considerable time was spent analyzing the available information sets.[54] However, in applying their Great Lakes model to the oceans, Resio and Vincent found an error: the model predicted more wave action than field data confirmed. It took three months to locate the source of error, but once the correction was made, Resio and Vincent had a model where "wave spectra in any depth of water adjust to a constant shape in wave number space." Theoretically, the model would work for bodies of water of all sizes.[55]

The Ocean Wave Information Study itself began with a technique basic to computer science and allied fields called the topdown concept. A schematic of various phenomena such as low pressure areas or thunderstorms was organized in scales and then applied to the wave action in three selected zones. Each required a different set of physics to model it properly: the deep ocean, where wave generation was best; the nearshore zone; and the surf zone, where research findings were at best tentative.

The study used a full ocean model that took pressure fields, transferred them first into winds and then into wind and wave interactions for the deep ocean, and then verified the findings by comparing the model outcome with ship observations. The two-dimensional spectra proved reliable for modeling the entire North Atlantic Ocean. From this point, the model was stepped down twice, first to an enlarged and more detailed study of the nearshore zone and then to a ten-mile segment of the coast. The process resembled the photographer's technique of highlighting details by making successive enlargements of a portion of a photograph. To acquire the more detailed information needed to focus on the nearshore zone, selected information from 20 years of hindcasts was fed into the model and then compared with the wave gages on the coast and in deep water.[56] The deepwater comparisons proved to be good. Data were organized and stored in a huge database, the Seastate Engineering Analysis System (SEAS). Here the thousands of indexed computer tapes could be accessed by engineers.[57]

As the Ocean Wave Information Study proved successful, CERC expanded its Coastal Field Data Collection Program, which existed to make Corps planners, designers, and operators aware of the available information, to include the Resio-Vincent hindcasting techniques. Supported by $700,000 in CERC funding, one part of the program aimed at obtaining ocean wave data. Although extensive wave gaging had been done on the South Atlantic coast and to some extent in the gulf, the measurements largely had been limited to sites where experiments had taken place or construction data were needed. In the first phase of the program, CERC used real wave data to verify the Atlantic Ocean deepwater hindcast data generated by the WDD and then adjusted it for shallow water. Phase two brought the deepwater data to the Continental Shelf, 10 to 30 miles offshore, at points about 30 miles apart. Phase three generated nearshore data at a minimum 20-foot depth for points about ten miles apart. Resio was confident of the system through phase two but felt the nearshore data had to be improved. The measurement program got underway

in May 1979 with data collected along the California coast. Later, the measurement program was enlarged to include the northwestern United States coast and, to some extent, Florida.[58]

A second element in the expanded Coastal Field Data Collection Program was the construction of beach profiles. This included collecting observations of the beach slope, breaker height, breaker directions, winds, and other information applicable to designing projects in an area. One of the initial findings of the ocean wave portion was that most of the sediment transport along the southern California coast was associated with four to six storms per year. This meant that if engineers modeled storm events correctly, they likely could determine the sediment budget (net gain from arriving material minus the net loss of departing sediment) at given sites.[59] In part due to the efforts of the San Diego Association of Governments, funds were appropriated in July 1981 for the Corps to undertake a comprehensive study of southern California. To provide a basis for coastal planning decisions, the Corps would develop a program to document long-term shoreline changes on a regional scale.[60]

Vincent later transferred from WES to the CERC to pursue research into wave propagation in shallow water. Progress in the field came rapidly. In 1976, a series of measurements were processed at Rijkswaterstaat in The Netherlands. In 1979, the Marine Remote Sensing Experiment collected data in the southern half of the North Sea.[61] In 1980, the American Atlantic Remote Sensing Land Ocean Experiment (ARSLOE) collected a 20,000 wave record database at a site open to the ocean. This provided Vincent with information on the low-frequency portion of the wave spectrum and wind field and the changes that occurred as the wave propagated from deep to shallow water, with or without wind.[62] While analyzing ARSLOE data, Vincent attended a conference to report on the European experiments. There he discussed with foreign scientists the similarities he had found within the data sets and his emerging hypothesis that the shape of growing wind wave spectra is regular, to a reasonable degree, and can be mathematically described.[63]

By 1985, researchers following this lead had combined similar elements within the three separate studies to indicate that wave growth in shallow seas also might be determined through familiar mathematical principles. One important conclusion was that the wind sea spectrum has important similarities, irrespective of water depth. Another was that the similarities imply that the relative balance of energy input, dissipation, and transfers within the spectrum are not influenced by bottom conditions. To engineers, the findings suggested that when determining the design characteristics of a coastal engineering structure, they could work confidently using only the wind field data.[64] For researchers, the findings led to the development of a self-similar, spectral-shape equation for waves in a finite water depth. With these, other shallow-water spectral models would be developed.[65]

Other WES Successes

Researchers in the WDD were producing theoretical and experimental studies at the frontiers of other specialties. The most dramatic advances were made in applying numerical theory in the modeling experiments of the Oregon Inlet Numerical Sediment Transport Study and in the area of tsunami research.

In 1978, the Wilmington District and the U.S. Park Service were embroiled in a technical controversy over a project for jetty construction and a sand-bypassing system at Oregon Inlet. The District claimed its project design would ensure the slowing of erosion. The Park Service and its consultants disagreed. Whalin believed a simulation was possible using available theoretical and numerical

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technology to formulate a numerical sediment transport model using data from the now successful Atlantic Coast Open Wave Information Study as the input wave climate. Such a study would compare both erosion and deposition for existing and after-project conditions for alternative sand bypassing schemes. No quantitative numerical coastal sediment transport study of this magnitude had ever been attempted. The study results bore out Whalin's conviction that complex numerical modeling simulations could be valuable assets to the Corps. The engineer who led the study was James R. Houston, later to follow Whalin as Chief of CERC.[66]

The tsunami is one of the most destructive water waves occurring in nature. The waves are generated by undersea earthquakes of magnitudes greater than 6.5 on the Richter scale. Typically, they are less than one foot high in the deep ocean, have wave periods varying from five minutes to several hours, and can travel at speeds of more than 500 miles an hour. When tsunami waves approach a coastal region where the water depth decreases rapidly, they are apt to appear as rapidly rising water levels and can cause immense loss of life and destruction of property. To provide the Corps with an instrument to delineate the inundation limits of tsunamis, Houston devised a numerical model to deal with the problem of tsunami propagation from the deep ocean to the coasts, first for the Hawaiian Islands and then for the Pacific coast of the United States.[67]

Coastal Engineering Research Center

As the Wave Dynamics Division emerged as a laboratory capable of producing innovations in coastal zone research, OCE personnel decided that CERC operations needed improvement. This resulted partly from the fact that OCE was becoming more familiar with CERC and how it operated. At Dalecarlia, CERC had been isolated and out of direct daily contact with other Corps organizations. The situation was reversed at Fort Belvoir. As contacts increased, CERC lost its mystery.[68]

Many at OCE believed that CERC did only a limited amount of reimbursable work and was not in touch with the field. In turn, some field organizations viewed CERC as too academic and inward-looking. Consequently, the Divisions and Districts became less aware of CERC's capabilities. Many CERC staff assumed that the Districts should apply whatever the Center was developing. Many at OCE thought CERC should be more customer conscious. The Center also had not found the satisfactory marriage between theoretical and applied research. "What are they doing?" became a common question. The CERC acknowledged its problems in responding to District needs, but regarded these as unfortunate difficulties associated with getting fully operational after the move from Dalecarlia. The Center acknowledged its problems in coordinating with WES too, but discounted the seriousness of the questions which were being raised.[69]

As these issues were brought to the attention of the staff in the late 1970s, CERC began to orient its work more to meeting Corps needs. In 1978, CERC reordered its research program to concentrate on such areas as shore-beach control; flood and storm protection; harbor, coastal, and offshore structures; and navigation improvement and recreation. The Center began developing two new ways to transfer research findings into technology useful in the field. Field Guidance Letters summarized the results of particular studies, and a Coastal Design Notebook gave practical advice.[70]

In 1980, CERC began publishing Coastal Engineering Technical Aids (CETA), how to publications for the field. One presented linear refraction computer program models. A CERC technical report summarized the wave data collected over the past 20 years covering much of the South Atlantic coast and some of the gulf coast. Another CETA, on limited wave height, suggested where Districts might save on construction costs.[71]

However, CERC's situation had changed. The WDD at WES had become a competitor in coastal-zone research; now the Corps had two laboratories capable of doing similar work.

VI

DECISION TO RELOCATE CERC

As the Wave Dynamics Division improved its research programs, observers in OCE concluded that WES could do the work for the Districts that CERC was not doing. One example involved the Detroit District's search for a solution to a wave problem. First, the District contacted WES, and WES referred the District to CERC, which replied it did not have the gages to acquire the needed data. The District then asked about running the Great Lakes model hindcast data. The CERC responded that the results from that kind of study would be difficult to support. The District then turned back to WES, which procured the gages and carried out the study. When the Directorate of Research and Development asked why CERC had not been able to respond, Colonel Ted Bishop, CERC Commander, replied that if the Center were to be the Corps' "wave experts," it should not be on call to fulfill any Corps need but should meet only special requests. The DORD viewed the response as typifying CERC's problems in meeting Corps needs.[1] According to an internal memorandum written by C. Linwood Vincent (now at CERC), the incident illustrated not only that CERC lacked the capacity to respond quickly to this type of data collection request but that WES was better equipped than CERC to provide hindcasts.[2]

By May 1978, WES was reporting that its Wave Dynamics Division had work units involved in seven areas that CERC thought had been reserved to the Center. The CERC Commander Colonel John H. Cousins claimed that WES was duplicating basic research carried out by CERC. He asked OCE to assign the field responsibility for the coastal engineering program to CERC.[3] The WES Commander Colonel John L. Cannon rebutted that while CERC had full management of the coastal engineering research program, WES was to conduct the site-specific reimbursable coastal engineering work for the Corps Divisions and Districts. This involved a combination of field studies and physical and numerical modeling, represented about one-quarter of the workload at the WES Hydraulics Laboratory, and resulted in the acquisition of reliable and comprehensive prototype data. Cannon said that while these researchlike missions could be transferred to CERC, the Corps would incur the costs of constructing facilities at Fort Belvoir duplicating those at WES requiring approximately \$5.2 million in capital equipment and \$1.5 million in laboratory equipment and hiring some 40 additional people.

The most prudent solution, Cannon suggested, was to let WES manage its own research program.[4] On other points, Cannon was more emphatic. Reporting to the Directorate of Research and Development in a separate letter, which reflects drafting assistance from WDD, he stated that ". . . essentially all recent advances and improvements in physical hydraulic model technology in the U.S., as well as most advances in numerical modeling techniques for application to CE problems, have occurred at or through the instigation of WES."[5] The dispute caused OCE to reappraise the respective laboratory missions. The resulting OCE decision appeared to validate the CERC contentions that the Center should be the Corps' primary facility for coastal research, that research should be defined broadly to include inquiry into basic phenomena, and that CERC's mission differed from those of the other laboratories. In 1978, OCE issued an Engineer Regulation defining the CERC mission statement in terms nearly as broad as CERC's 1963 charter. At CERC the outcome was hailed as a victory.[6]

Budget Imperatives

Major economic problems began to appear in the late 1960s as the Nation dealt with deficit budgets while financing the Vietnam War. By 1973, worsening economic conditions had yielded annual 10-percent inflation and unemployment rates. In the winter of 1973-1974, the Arab nations that domi-

nated the Organization of Petroleum Exporting Countries (OPEC) began using oil as a diplomatic weapon. Fuel prices soared. In 1977, 1978, and 1979, omnibus water resources bills failed to pass Congress. A movement to cut government budgets – dubbed Proposition 13 fever after the California referendum initiative – swept the country. By the late 1970s, the Corps faced serious funding problems.

About half the Corps budget was related to construction, which depends heavily on fuel. In a typical Corps construction contract, fuel would account for 20 to 30 percent of the costs. When fuel costs rose sharply again in 1979, the Corps found itself about $240 million short in meeting its obligations.[7]

The Corps' R&D budgets had not anticipated these economic conditions. In October 1972, OCE had laid an R&D program before the Office of Management and Budget (OMB) that called for spending $14.5 million in FY 1974 and increasing that figure by approximately 20 percent annually over the next five years, a research program totaling some $125 million. The CERC planning had been based on these figures. Consequently, while in 1972-1974 CERC budgets rose in constant dollars, they decreased in real dollars due to inflation. Meanwhile, CERC's fixed operating costs rose. At Fort Belvoir, the charges for operating the wave tank went from approximately $200 per hour to over $600 per hour. Because CERC was the facilities manager of the Kingman Building complex (now called the Humphreys Engineer Center), 10 to 12 people had to be allocated to this duty. The administrative work took more time and positions than CERC was budgeting, and the Commander's time was reduced by the need to run the Fort Belvoir complex. With more budget supporting routine organizational operations, CERC research suffered.[8]

In 1976, OCE increased CERC budgets approximately 15 percent.[9] It was not enough. In May, the CERB reviewed the CERC program and expressed concern over the absence of resources:

> . . . The Corps is the major United States researcher in coastal engineering and has long been a recognized world leader in the field. The state of the art in coastal engineering, relative to other areas researched by the Corps, is not well advanced. The Corps' laboratory facilities and staff capabilities for coastal engineering research are certainly unequaled in the United States and probably in the world. Present funding levels do not permit full and efficient exploitation of these resources. Because of the Corps' preeminence in the field, a constraint on Corps' coastal engineering research translates on a nearly one to one ratio to a constraint on United States coastal engineering research. The long range effects are likely to be quite critical.[10]

But OCE could not provide more funding. All the Corps programs were being scaled down, and there was considerable competition for the available money. In 1976 and after, CERC's requests did not prosper before the Corps' Civil Works Review Committee.[11]

In 1978, OMB proposed cutting $1.6 million from the Corps' FY 1980 coastal engineering research program because the figure appeared excessive in proportion to the number and cost of Corps beach erosion projects. Arguing against the cuts, Thorndike Saville, Jr., CERC Technical Director, pointed out that, based on the engineer building cost indices (FY 1972-1979 at 1.7 times), the 1972 appropriation for Corps coastal engineering research ($4,275,000) represented $7,265,000 in current dollars. The $7 million total research appropriation requested for 1980 thus was an actual decrease in real dollars over the seven-year period.[12]

Some at CERC perceived a different problem. The cuts, they felt, could be traced to a desire within the Civil Works Directorate to lower funding for CERC projects and use the money elsewhere. They pointed to the 1979 mission problem statements for research and development (the Corps' official priority rating) which included 35 items directly related to coastal engineering. Four of these ranked in the top ten, nineteen in the first fifty, and all but five were in the upper half. That rating of research needs stood in striking contrast to the research priorities within the Civil Works Directorate, where, in ranking the 28 research areas, the staff placed all coastal research in the lower half.[13] To the internal struggles within Civil Works was added the Chief of Engineers' emphatic statement that he intended to protect the mobilization-related missions in the budget first. If something had to give, it would not be emergency preparedness.[14]

Budget decisions now began to reflect CERC's eroding power base in the Corps. Prior to the establishment of the R&D, CERC commanders and technical directors could defend their programs at all

levels in the Corps and before the Bureau of the Budget and before congressional committees.[15] Now the RDO made budget decisions and fought the battles. In theory, under the new system, civil works program budget requests were generated at the laboratory level, forwarded to RDO for review and approval, then went to the Civil Works Directorate, and finally were forwarded to OCE prior to their submission to OMB. In practice, planning budgets reflected not only needs and resources but also what would probably be supported in the President's budget.[16]

Long-term CERC research projects and data collection programs suffered as the budgets decreased and priorities changed. At a 1979 meeting of the CERB, Major General E. R. Heiberg III, the board president and Director of Civil Works, agreed that projects with identifiable research needs should be rated higher than general research projects. A commentator suggested that instead of concentrating on short-term applications, CERC research should anticipate future problems. At a CERB meeting the next year, the director of the Corps' Directorate of Research and Development noted that even though basic research might save many times its investment, in the avoidance of future outlays, the fact was that the Civil Works director tells the DORD "what the recommended priorities are and the funding level, and we do essentially what Civil Works requests us to do."[17]

Particularly frustrating to CERC researchers was the fact that only limited funds were available to gather data essential to project design. However, if a problem developed after a project was constructed, vast amounts of money were available to correct the error. Just as medical experts argued that spending money to prevent illness cost less than treatment, CERC contended that data collection while projects were still in the design stage would save money in the long run. A related issue was that in the CERC budget no distinction was made between data collection and expenditures for other types of research. Why, asked CERC and CERB, should the necessary data collection programs be called research? The Center was handicapped by the language of the people in the budget business, declared participants at a 1980 CERB meeting; nobody in the Corps understood the entire research process or acted with long-range goals in mind. The Corps' R&D program had been level funded at approximately 1 percent of the Civil Works budget since 1975, replied the Directorate of Research and Development (DRD) director, and no more money was available. (His figure did not include reimbursable work.) General Heiberg added that the Government gave the Corps an annual budget number. Everything had to fit into that. The process was agonizing, and it was the same every year.[18]

New administrative systems were imposed on CERC as OCE began exercising more oversight. To some CERC staff, this was micro-management that not only failed to control expenditures but made it more difficult to get things done. They cited examples. In April 1978, the Norfolk and Baltimore Districts asked CERC to produce a shore protection pamphlet. Four months later CERC forwarded a draft that was completely satisfactory to the Districts. Then OCE took 13 months to review the pamphlet and return comments. The original plan was to supply camera-ready copies to the Districts for local printing. This idea was abandoned in favor of publication and public distribution by the Government Printing Office (GPO). Making that decision took five months. As a result, additional reviews were now required. Two years after the initial request, the product informally promised by CERC had not been delivered to the District.[19] "When I began my second six months as CERC commander and director," Bishop wrote James Choromokos, Jr., Director of DRD,

> . . . we entered the 1981 budgeting process where internally we reviewed what CERC had done in the past and what we thought should be done in the future in coastal engineering. From that we proceeded into the RDRB (Research and Development Review Board), then into the program reviews, and most recently through a series of frustrating, confusing budget reduction exercises. . . . With the volume of information that is now provided to OCE, and your cover letter which indicated that you need more information for making meaningful management decisions at the OCE level, it appears that day-to-day internal management of the crucial resources-manpower and money–must take second position to reporting statistics to OCE.[20]

Bishop's frustration reflected something far more serious than the question of how much information was needed to make a decision about a research program. The budget crisis that had de-

scended on the Corps now was threatening CERC's existence.

Budget Pressures on CERC

The funding problems of CERC had become critical in 1979. Though the deputy director of Civil Works was willing to support requests for coastal engineering research of $7.0 and $7.6 million respectively for FY 1981 and 1982, the appropriation FY 1981 was $6.87 million; for FY 1982, $6.72 million; and for FY 1983, $6.66 million. Of that funding, approximately $1 million of the general investigation coastal research and development funding was earmarked for WES research. Bishop pointed out that, in addition to budget cuts, an increasing proportion of CERC's coastal research and development funding was required to repay the revolving fund. At the same time, he said, OCE was directing the RDO and CERC to continue upgrading research facilities and to support equipment to at least state of the art.

Still, CERC's equipment needs had become so critical that the Center could not serve the Districts as before. The large wave tank, for example, had been state-of-the-art research technology in the 1950s, 1960s, and into the 1970s, but by the late 1970s it had less application. The Center required new wave generators ($700,000), a tidal system ($200,000) for the closed shore processes test basin, and a wave generator for the large wave tank ($500,000 to $1 million). By 1980, the essential facility improvements at CERC totaled between $2,850,000 and $3,350,000.[21] However, the funds were not forthcoming.

The money problems facing CERC were similar to those that other Corps elements were addressing, but in CERC's case the issue was more acute. Unlike the WES, CERC could not fall back on a system of combining research goals with reimbursable work done for other agencies. Nor could CERC count on finding support funds by moving aggressively to do more reimbursable work. At a 1979 meeting of the CERB, Neill Parker had reported that to engage in more reimbursable work, CERC would need to hire more people. The net result would be that any additional income would be eaten up by the increased expenses. For example, most of the approximately $1 million for reimbursable work CERC had received in 1979 had simply passed through CERC's checking account to contractors.

The real problem was that the Center received numerous requests from the Districts and Divisions to do routine engineering but did not have the personnel or equipment to comply promptly. Parker concluded that CERC lacked the physical equipment to become a high-quality, wide-ranging technical support facility but, given the personnel and their collective experience, the Center did have the competence to become the Corps' Center for sophisticated undertakings, to provide technical guidance and technical support at a senior level for Corps projects, and to carry out the specialized research not being done elsewhere. Parker's closing statement was less reassuring. Until basic equipment needs were met, CERC could not re-emerge as the center of expertise in coastal engineering.[22]

Parker's factual definition of CERC's dilemma confirmed fears that others had reached intuitively. Already, CERC and its advocates within the Corps were arguing that the Civil Works Directorate undermined Corps research policies and plans with inadequate budgets and little recognition of coastal engineering projects. These arguments changed nothing.[23] Corps laboratories came under increased pressure to offset declining research budgets by doing more reimbursable work. They needed to aggressively solicit projects from the Districts and Divisions.[25]

On 9 and 10 June 1980, in response to a special request from Bishop, the civilian members of the CERB met in Cleveland to examine the overall coastal engineering program. The meeting focused on specific questions Bishop submitted and the budgets for FY 1980 and 1981.[25] The discussions yielded no solutions to CERC's budget dilemma. Hamstrung, CERC now sought policy guidance from DORD.[26]

As yet, CERC's problems had not engaged the attention of the Chief of Engineers or other top-level decisionmakers. Thus, the crucial decision was made within the Directorate of Research and Development. The issue emerged in 1978 when Robert Whalin's plans to upgrade equipment in the WDD had progressed to the point where WES had budgeted for a multidirectional spectral wave generator to be paid for through reimbursable work. The CERC objected to the proposed expenditure because under present circumstances the Corps could afford only one extremely expensive wave testing system. Furthermore, funding the new wave generator at WES meant CERC's shore processes test basin would remain in its current useless condition.

In early 1979, interim DORD Director Colonel Maxim Kovel decided to support the WES proposal. In essence, his decision overturned that made by OCE the previous year when its 1978 Engineer Regulation reaffirmed CERC's primacy in performing Corps' coastal research. In effect, Kovel's action relegated CERC to the position of an inferior laboratory. While not providing a clear answer, DORD documentation suggests that Kovel judged the WES proposal more cost effective because WES could pay for the generator out of reimbursable funds, but CERC could not.[27]

Dismantling CERC

The series of decisions that culminated in CERC's relocation as a WES laboratory reflected organizational pressures affecting the Corps. The basis for the decision dated back to 1963. That year a Bureau of the Budget circular described the criteria for carrying out plans set forth in a 1962 presidential memorandum intended to limit the number of Federal employees in the National Capital Region. (Federal employment was not to exceed 450,000 by the year 2000 and Federal activities not essential to the seat of government were to be decentralized.)[28] In 1979, OMB Director James T. McIntyre, Jr., advised the executive departments and agencies that the Civil Service Reform Act of 1978 (Public Law 95-454) required him to conduct a detailed study of decentralization of Federal governmental functions.[29] The Corps was asked to respond to the OMB request in May 1979. In June, an edgy Colonel Ted Bishop asked if CERC had been identified as a candidate for relocation.[30] His inquiry reflected the unease that had spread through CERC.

The man who would make the decision and carry out the relocation of CERC, James Choromokos, Jr., arrived at OCE in September 1979. Born in Chicago, Illinois, Choromokos received his civil engineering degree from the University of Miami in 1953 and then entered the U.S. Air Force. He served 23 years, retiring as a colonel in 1976. In the service, he obtained M.E. and Ph.D. degrees from the University of Wyoming. Choromokos divided his Air Force career between civil engineering and managing research and development programs. In 1976, he went to the Illinois Institute of Technology, where he formed the construction management program. When he came to head DORD, he knew something of the Weapons Effect Laboratory at WES, but little of the Corps' other laboratories. This did not matter. Choromokos was picked not to expand the Corps' research operations but to reorganize them within the confines of new budget realities.[31]

It took a year for Choromokos to settle in and feel comfortable in his new position. To orient himself, he visited the Corps laboratories. His impression of CERC was that it was searching for a mission. While CERC had considerable technical and computer capability, it was too small to compete with WES. The Center was collecting but not using data for any broad theoretical purpose. Choromokos felt that CERC was doing experiments without knowing why. He was not impressed with CERC's large wave tank, nor was he when he walked into the Kingman Building and heard the CERC complex referred to as "a campus." Little at CERC fitted Choromokos' concept of an Army laboratory.[32]

By contrast, Choromokos found WES to be a large and able organization. He termed it "responsive, quick, overwhelmed with reimbursable work, and composed of go-getters who were inclined to view the Directorate of Research and Development as an obstacle to their progress." On 18 December 1979, Choromokos met with the laboratory commanders and technical directors and DORD staff to share his philosophy. Privately, he already had concluded that the cost of doing business at CERC was too high. With tightening of operational funds and manpower spaces, Choromokos calculated that the Corps could no longer afford to maintain CERC as a separate research center. In early 1980, a study commissioned by Choromokos suggested changing CERC's management and moving the operation to WES. In October, Choromokos decided to move CERC. Short of a vast increase in Federal funding for coastal research, nothing would have changed his mind.[33]

In 1981, the Corps was directed to reduce personnel by 10 percent. The cut was across the board. The DORD staff was to be reduced by 130 or more positions. (Cuts in research amounted to 14 percent of the Corps' personnel cutback.) Choromokos now asked CERC to provide his office with information regarding a potential move to WES.[34]

In response, Bishop recommended creating a new coastal laboratory (to be the fifth research laboratory at WES) and placing in it the CERC divisions involved in wave-sediment, wave-structure, and sediment-structure interaction. The laboratory also would take on the work of the WES Wave Dynamics Division in the WES Hydraulics Laboratory. The

reorganization, said Bishop, would account for five of the six line branches at CERC. The remaining Ecology Branch would become a new branch in the WES Environmental Laboratory. The Field Research Facility at Duck, North Carolina, would not be affected. The CERC's administrative and support elements would be disbanded. As for the impact on mission and personnel, Bishop speculated that fewer than 30 percent of the senior people would move to Vicksburg. The CERC large wave tank would be lost to the Corps, as would the shore processes test basin. The CERC's administrative support of Corps facilities at Fort Belvoir would have to be replaced. Because 98 positions would be transferred to Vicksburg, the Corps' savings in manpower would total 48 positions.[35] Later, Bishop would estimate the cost of the move at $1.3 million.[36]

In April 1981, an in-house DORD study addressed the problem of accomplishing "essential coastal research and field consulting in the most efficient way." Assessing the quality of coastal research the Corps required for the next ten years, the study assumed that budget levels would remain at about $6.7 million in constant dollars, that civil research and manpower authorizations would allow CERC to continue as a viable laboratory, and that the obligation to repay the revolving fund for CERC facilities would continue.

Among the facts bearing on the problem, as DORD defined it, were the obsolescence and deterioration of key laboratory facilities at CERC, which degraded CERC's capability for research and reimbursable work; the concern and controversy over dividing coastal research work between CERC and WES; and the fact that with the emergence of the Wave Dynamics Division at WES, the Corps appeared to have developed parallel coastal engineering facilities. The study speculated that the problems in coordinating coastal research and reimbursable work between CERC and WES would worsen, affecting both the laboratories and field users. The most critical problem was the anticipated divergence between fixed budgets and rising costs through the 1980s. The study examined four alternatives and concluded that eliminating the coastal research capability at Fort Belvoir and reconstituting CERC at WES would be the best solution.[37]

On 1 October 1981, Budget Director David Stockman targeted the Corps for a reduction in force. On October 17, Choromokos requested approval to move CERC. Consistent with the data he had received from Bishop in March, he calculated that 48 positions would be saved if 98 were shifted to WES and only 50 people moved. Driven by budgetary imperatives and his own judgment of the quality of the work done at CERC, Choromokos was more than willing to disassemble CERC and rebuild it at Vicksburg.[38] General Heiberg, the Director of Civil Works, concurred in November that consolidating the laboratories was the correct decision.[39]

The CERB met on 16-18 November at WES and during the executive session was informed of the pending change.[40] On 4 December 1981, CERC personnel were told officially that the "possible movement of CERC to WES is being studied." Careful phrasing implied that no decision had been made, but the people at CERC knew better.[41] The Chief of Engineers approved the move on 23 February 1982.[42]

Subsequent discussions within DORD ratified Choromokos's decision. An internal memo written in December evaluating a possible CERC move to WES had indicated that Fort Belvoir had no facilities that would compel the Corps to keep CERC there. The 3- by 15-foot concrete wave tank in the J. V. Hall Laboratory Building would be replaced by three WES wave tanks. The large wave tank at Fort Belvoir would be lost if CERC moved, but the United States had two other large wave tanks. The shore processes test basin at Fort Belvoir had been closed for a year and a half because of CERC's inability to fund the repayment costs for new wave generators required to update the facility. The tidal inlet facility at WES could be used in the place of the moribund SPTB. These and all other problems associated with a move were solvable.[43]

At the time the decision that CERC should be moved was made, Choromokos rated the probability of any transfer taking place at a 50-50 chance. He asked each of the five final candidates for technical director if they were willing to go to Vicksburg. He selected Robert Whalin. His appointment was approved on 30 March. On 3 May, Whalin reported to Fort Belvoir. To protect him with CERC employees, Choromokos deliberately kept Whalin out of all planning for the move.[44]

Bishop had mounted a spirited defense for retaining CERC at Fort Belvoir. The Corps had made the important decision to locate in the Kingman complex a modern, efficient coastal engineering research laboratory, he wrote in a lengthy memorandum in

early December 1981. The long-term master plan at the time that decision was made called for improving CERC's facilities. Over the years, CERC had built up a well-educated, highly motivated multidisciplinary staff whose expertise was unmatched in the United States and possibly in the world. Successive chiefs of civil works and chiefs of research and development had supported budget and manpower levels to gradually increase CERC's capabilities.

When the issue of moving CERC to WES had arisen, morale at CERC had suffered substantially. The decision had never been analyzed thoroughly, Bishop said, and the option paper prepared by the DORD staff contained little in the way of hard facts. The best way to save money and operate more efficiently would be to absorb the WDD into CERC, a relatively simple change.[45] To this suggestion, Choromokos made no response.[46]

The Move to Vicksburg

The Directorate of Research and Development planned to relocate CERC quickly. The move was to be effective 1 October 1982. Some 89 of the 98 positions were to be shifted to WES. The nine positions at the Field Research Facility at Duck, North Carolina, would be retained there. About 30 support positions at the Kingman Building would be transferred to the Corps in downtown Washington, D.C. Choromokos made very conservative estimates of the savings and costs that would be associated with moving CERC to WES because he wanted to be in a strong position if he had to weather a Congressional investigation or General Accounting Office inquiry.[47]

Few secrets are kept in any large organization. Although DORD had included no CERC staff in the discussions leading the move, everyone knew what was coming. Bishop advised Choromokos on 9 March that unless action was taken quickly, like identifying needed personnel, key people would be lost. At a scheduled meeting at Fort Belvoir, Choromokos told CERC staff of the 1 October moving date and assured them that all personnel would have ample time to decide whether or not to go and to plan accordingly. Ten days later the WES personnel staff held a second meeting, which was a disaster. Speakers shocked CERC employees by telling them they had just one month to make plans. The CERC staffers exploded from the room in anger and jammed the phone lines to Virginia Congressman Stanford E. Parris. The WES staff scurried back to Vicksburg.[48]

The poorly handled and blunt announcement that CERC staff had just a month to rearrange their lives caused a public outcry and ultimately cost the Corps considerable time and money. Parris, Virginia's Eighth District Congressman and a second-term Republican, contacted Secretary of the Army John Marsh, a former Virginia Congressman, on 17 March. Not mollified by Marsh's explanation that came on 6 April (and had been prepared in OCE), that consolidating the Corps' laboratories would result in a temporary loss of 30 employees but a long-term net increase of 104 employees at Fort Belvoir, Parris pressed the matter.[49]

The Corps publicly announced the planned move on 9 April. On the 13 April, Parris met with Marsh and received assurances that the Army Secretary would look into plans. Within a week, Marsh had asked the Corps to initiate a restudy. Parris meanwhile launched a broad campaign to block the transfer. All ten Virginia Congressmen, together with Senators John W. Warner and Harry F. Byrd, wrote the Secretary of the Army protesting the proposed change. Parris claimed that "the Corps plans to move its entire Coastal Engineering Study [sic] Center to Vicksburg to satisfy a 'hotshot' engineer it wants to hire as the center director."[50]

The move would cost Fairfax County 100 jobs and $4 million yearly in local sales and cost the Government $2.6 million in moving expenses, Parris declared. But he also acknowledged that Mississippi Senator John Stennis, the ranking Democrat on the Senate Armed Services Committee and one of the Senate's most powerful members, might have enough influence to force CERC's transfer to Vicksburg.[51]

Unhappy CERC employees brought political pressure to have either OCE or Congress reverse the decision. The most comprehensive presentation was by Frederick Camfield of CERC, who advised Senator Warner that the Corps' "fact sheet was poorly prepared and seemed to contain various errors and omissions." Camfield passed along comments supplied by a number of CERC employees. He disputed DORD's contentions that CERC equipment was technologically outdated, needed replacing, and was not being fully used. Camfield pointed out that OCE had not allowed CERC to buy the generators it needed for the shore processes test basin, but had

approved similar funding for WES. He argued that the coastal research and tests requiring a large wave tank could not be done if the facility were abandoned. He attacked the Corps' plan to reduce funds for coastal research and development at a time when more people were moving into the coastal zone. Claiming the move was not cost efficient, he pointed out that because few key people would move to Vicksburg, the scientists, engineers, and technicians and their cumulative expertise would be lost to the Corps.[52]

In the contest between DORD and CERC to see who would influence OCE, DORD controlled the agenda. CERC advocates were able to win only a delay. As a result of the political sensitivity of relocating the facility in an election year, the Corps was asked to postpone the transfer until after the 1982 Congressional elections. However, as soon as the elections were over, Choromokos initiated the move. He later said that the timing of the announcement, just before the Christmas break, was unfortunate but necessary; the people at CERC had to be informed.[53] Again Parris rallied the Virginia Congressional delegation. He also tried to get the House of Representatives to block funding for the move. The inability of Congress to adopt a budget in the fall prevented that action, and neither Budget Director David Stockman nor Representative Walter B. Jones, a North Carolina Democrat and chairman of the Committee on Merchant Marine and Fisheries, responded to Parris's pleas to intervene.

At the same time, Mississippi's Senator Stennis and Representative Jamie Whitten pushed for the move. On 16 December, the Secretary of the Army again gave his approval. The CERC employees were informed the same day that the Center would be transferred to Vicksburg, population 25,434 (one twenty-fifth the size of Fairfax County, Virginia). Choromokos visited CERC on 16 December prior to distribution of the news release to explain that all jobs were secure. The question and answer session was heated. The CERC employees were given official personnel transfer of function letters on 11 January 1983 with responses due back by 9 February. The Military Traffic Management Command began coordinating the transfer of equipment in a move expected to cost $1.442 million.[54]

The CERC employees continued to protest what they claimed was the dismantling of a cadre of scientists at the forefront of coastline research in the United States. According to their estimates, as much as $336,000 of CERC's annual operating budget of $7 million had been siphoned off each year to pay for the eventual replacement of buildings and laboratories. As a result, they claimed, the indoor model test basin, built in 1972 at a cost of $3.7 million, had to be closed in April 1980, after being used for just two experiments. (This was to save CERC $100,000 a year under the payback system.) When queried about this, the Corps replied that the Carter administration had been responsible for the reduced funding that had affected CERC. Parris continued to oppose the move, accusing the Corps "of throwing $14 million down the rat hole and making the move primarily for political reasons and the convenience of its new technical director."[55] Choromokos called Parris's charges "outrageous." The move, he said, "was made not for political reasons but for efficiency and economy . . . I hired Whalin . . . and there was no promise or anything like that made."[56] The documented record supports Choromokos' version of the events.

On 15 February 1983, CERC released a Realignment Fact Sheet explaining the transfer. Funding difficulties and the decreasing emphasis on coastal engineering research had led to a reevaluation of the organization and management of the total research program. A decision had been made to consolidate all Corps coastal research in one location. Waterways Experiment Station was selected because the hydraulic research facilities were more modern and extensive than those at CERC. The transfer action would affect 135 full-time permanent civilian positions: 79 would be transferred to WES; 30 to the Humphreys Engineer Center Support Activity; 9 would remain at their current duty station in Duck, North Carolina; and 17 positions would be abolished. Eliminating the 17 positions would save approximately $555,000 per year. The Corps would offer all current, full-time employees continued employment. Economic and environmental impacts were predicted to be minimal in both Virginia and Mississippi. Taxpayers were reassured that the Corps planned no new construction.[57]

The fact sheet went on to state that the CERC large wave tank, with a depreciated value of $1.14 million, had limited utility.[58] The 140- by 15- by 4-foot concrete wave tank built in 1976 would be abandoned. The computer-controlled spectral wave generator, valued at $444,000, and associated instrumentation, which had cost approximately $60,000, would be moved and retrofitted on an existing wave

tank at WES. Two glass wave tanks, each 150 feet long, 3 feet deep, and 1.5 feet wide, valued at $351,000, would be relocated with their associated spectral wave generators for continued use at WES. The costs were not specified for the plans to convert the shore process test basin into needed storage space for the Corps' publications depot and the Corps' museum and historical warehouse.[59] (This conversion did not occur.)

The Directorate of Research and Development asked WES to put together a transition assistance team to answer questions about the move to Vicksburg. Few sought their services, and a high percentage of scientists and engineers left CERC. Of the 83 people offered transfer of function to WES, 38 initially responded "yes," but fewer than 24 actually moved. Of these, two had been hired from WES in 1982 and one had been hired at CERC for transfer to WES.[60]

Analysis

Just as CERC readied itself to expand and play a larger research role, external factors undermined and constrained that capability. First, plans were made elsewhere in the Corps to expand the facilities at the Dalecarlia reservation in the District of Columbia, home of the Beach Erosion Board. When these plans were opposed, decisionmakers in OCE failed to examine the fundamental issues closely. If CERC were expected to expand slowly, it could have been kept at Dalecarlia longer. If CERC were to become a much larger operation in the near future, it should have been moved to Fort Belvoir more quickly. If CERC were to undergo only limited expansion over the next four or five years, the best option would have been to reserve the Fort Belvoir site and leave CERC at Dalecarlia until adequate funds for new facilities were assured. The record suggests that OCE intended for CERC to expand rapidly.

The decision to move CERC was made after an OCE command inspection in December 1967 concluded that Dalecarlia had insufficient space for the CERC of the future. The budget-driven plans contained a fatal flaw. Though some CERC equipment was almost obsolete, the construction of the Fort Belvoir complex was based on an understanding that the Corps would re-create CERC facilities but would not underwrite major improvements. The move itself ran over budget, and acquisition of new equipment required for minimal upgrading was delayed; by 1975, when the move was completed, CERC had passed through years of organizational instability and work disruption.

The Coastal Engineering Research Center now had new financial obligations. Facilities construction at Fort Belvoir was financed through the Corps' revolving fund, a line item in the OCE budget that enabled Divisions, Districts, and other Corps elements to "borrow" money for capital expenditures. Yet, though rising in constant dollars, CERC budgets decreased consistently in real dollars in 1972, 1973, and 1974 due to inflation. Meanwhile, fixed operating costs rose as a consequence of the move and because CERC was the facilities manager of the Kingman Building complex. To these debt burdens was soon added the $6 million cost of acquiring the Field Research Facility. Concerned about the impact of rising fixed costs on research efforts, the CERB reviewed the coastal engineering program in 1976 and asked for a major increase in CERC funding.

The timing was not propitious. Beginning in the mid-1960s, the Corps of Engineers had gone through a period of organizational restructuring. Changes in the budgeting process began when the Planning-Programming-Budgeting System was introduced into the Corps in March 1965. In July, a Policy and Analysis Division was created. It soon extended PPBS to all civil works activities, including research. In 1971, the Assistant Secretary of the Army for Research and Development said he wanted better planning in Army laboratories. This was followed by an Army Regulation requiring that program plans include cost figures so that research projects could be compared. Then and later, CERC researchers would debate whether this was the most meaningful standard for comparing projects, but they had no audience at OCE.

Next, Chief of Engineers Lieutenant General William C. Gribble set plans in motion that ultimately resulted in the creation of the Directorate of Research and Development. In time, DORD had a primary organizational effect on CERC. The new research and development structure began to generate policies that dictated appropriate areas for Corps research and set priorities for funding. These policies differed appreciably from the 1963 OCE emphasis on the coastal zone and, of course, changed CERC responsibilities.

While CERC's situation at this point might be compared with that of a badly undercapitalized business, the Center faced no real problems in dealing

with OCE so long as it had no competition. However, that condition was changing. Simultaneously with the onset of CERC's move-related troubles, WES began developing capabilities that rivaled CERC's. In 1971, Robert W. Whalin became Chief of the Wave Dynamic Division at WES. In January 1974, in a reorganization he promoted, the General Investigation Tidal Inlets research program was transferred to his division. Thus, all coastal inlet work was centralized. Ambitious to make WDD the best facility of its kind and well versed in new statistical methodologies, Whalin used site-specific, reimbursable work as a means to move into areas combining basic research with the need to solve particular Corps problems.

There were two obstacles to the growth of WDD. The first was that to become the leader in the field, WDD would have to recruit those qualified in applying numerical modeling techniques. This required the promise of new and interesting projects. The second problem was that WDD would have to convince the directorate at WES and then OCE to support the acquisition of expensive, high-quality, unique facilities. Though none were in operation anywhere, Whalin wanted a test basin with a directional, spectral wave generator. The potential of an extraordinarily expensive construction project on the Great Lakes provided WDD with the opportunity to succeed.

The CERC Commander Colonel John H. Cousins, noting that WES was beginning to duplicate CERC in basic research, asked OCE to assign the field-level coastal engineering program to his organization. This prompted OCE to reappraise the respective laboratory missions. The outcome was an Engineer Regulation issued in 1978 that reestablished the CERC basic research mission in the original broad terms. Some at CERC hailed the decision as signifying the Center would be "the Corps' Office of Naval Research."

By the late 1970s, the Corps was strapped for resources, and the American economy was in decline. When fuel costs rose for a second time, in 1979, previously prepared budget programming and contracts left the Corps $240 million short in meeting its obligations. The Corps faced considerable pressure to cut expenses by realigning operations, and support for basic research studies waned as OCE budget-makers emphasized research applicable to specific construction.

Budget considerations were the critical factor when WES in 1979 asked for funds to build its multidirectional, spectral wave generator. Knowing the Corps could afford only one high-cost wave-testing system, CERC protested. Colonel Maxim Kovel, Interim Director of DORD, supported the WES proposal because the WES generator could be paid for out of reimbursable work. By placing the most modern equipment at WES, Kovel relegated CERC to the position of an inferior laboratory and, in effect, reversed the 1978 OCE Engineer Regulation reaffirming CERC's primacy in coastal zone research.

The financial situation of CERC worsened as an increasing proportion of the Center's funding went to repay the Corps revolving fund. Simultaneously, DORD and OCE were applying pressure on Corps laboratories to upgrade equipment to at least the state of the art. At CERC, these essential facility improvements would cost $2,850,000 to $3,350,000. A logical sequence of events followed. Anticipating future budget difficulties, in 1979 DORD Director Choromokos commissioned a study of CERC. It suggested that the facility be changed and relocated. Choromokos concluded that with WES and CERC having the same research capabilities, the cost of continuing to operate at Fort Belvoir was too high. By October 1980, he had made up his mind to move CERC to WES. Short of a vast increase in Federal funding for coastal research, nothing would have changed this decision.

In 1981, OMB directed the Corps to reduce personnel by 10 percent. The reduction did not affect all offices equally. DORD was cut by 14 percent and had to eliminate 130 or more positions. Hard decisions now had to be considered. The changed conditions in CERC's external organizational environment dictated the choices that were made. Under the circumstances, reconstituting CERC made financial and organizational sense, and outside CERC, there was little support for retaining the Center at Fort Belvoir.

VII

CONCLUSION

Research Legacy

The observation and data collection programs of the Coastal Engineering Research Center carried out during its tenure at Fort Belvoir built up an immense database. This increased knowledge regarding wave action and sand transport, the effects of tides and waves on shore erosion and accretion, sediment movement, inlet and estuary dynamics, and the effects of construction. The data also assisted engineers engaged in project planning by providing them with site-specific information.

Other CERC research programs spanning the years 1963-1983 had equally significant results. They advanced the capacity to compare different types of material and to quantify and predict sediment losses from the beaches. The Sand Inventory Program, begun as a search for exploitable deposits of sand and expanded geographically to include the Great Lakes as well as the oceans, became increasingly more sophisticated with the incorporation of new technology. The Center pioneered in economical methods of beach nourishment, using offshore sand deposits as the borrow sources, and refined techniques for transferring sand from offshore deposits to the beach zone. This included the first American tests of split-hull dump barges.

Research conducted at CERC's Prototype Experimental Groin Facility modernized groin engineering. The CERC deserves much of the credit for developing the methods for determining littoral transport and computing the physical design characteristics for weir jetties and then predicting the shoreline changes resulting from their construction. Basic research and the construction of a number of novel projects by CERC advanced the understanding of breakwater design. Studies by CERC guided the Corps in selecting sites and projects for demonstration projects in the five-year program to test and evaluate low-cost erosion control measures.

The Corps' enlightened attitude regarding the shoreline environment, particularly the Corps' stand favoring protection of the unspoiled barrier islands, reflected CERC recommendations and dovetailed with the Corps' reluctance to use Federal money to protect coastal development. When the potential development of the barrier islands became a political issue, CERC took the lead in addressing the technical and scientific questions about barrier island formation and the natural processes responsible for their dynamic nature.

The Center pioneered studies using vegetation to solve coastal engineering problems. By establishing a formal ecology program, CERC advanced knowledge of the effects on ecosystems of such activities as offshore dredging, beach borrow and fill, and ocean dumping. The program also provided information on the impact of construction-generated sediments on estuarine organisms and changes in the ocean environment resulting from offshore construction. Along with the work of other agencies, CERC's hurricane studies advanced knowledge of the effects of wave and storm surges on the coast.

Organizational Legacy

The Coastal Engineering Research Center's organizational life cycle provides valuable lessons. When it was created, CERC was the only Federal agency with a coastal zone research mission and was nearly alone in funding studies of waves and their effects. The Center's strength lay in its promise of fulfilling the expectations of its staff, the Coastal Engineering Research Board, and the Corps that CERC could do more and better research than the Beach Erosion Board. The Office of Chief of Engineers and CERC staff perceived that while direct benefits accruing from basic research were difficult to translate into exact dollar values (such things as improved safety, convenience, lesser degree of risk, and greater protective capability were difficult to

quantify), basic research paid off handsomely. Advocates claimed returns of 10 percent of program costs in the Corps budget.

The early 1960s were years of expanding missions, budgets, and prospects for the Corps. No one in OCE or elsewhere in the Federal establishment suggested that CERC should plan conservatively for research or its future as an independent laboratory. The CERC activities thus assumed an ever-widening research mission. As a result, staff assumed many things: CERC would commit to research that would produce long-range benefits. The CERB would be the primary source of advice to the Chief of Engineers on coastal zone research. The CERC would have its separate line item, or something like it, in the Corps budget and would remain favorably positioned in the research budgeting process. Because the coastal zone was an important yet little-studied area of expanding public and Federal interest, the Corps would support CERC research over the long term. These assumptions were fundamental to CERC planning, and over time all proved invalid.

Organizational crises do not announce their beginnings. They do not burst upon the scene but rather creep in, most commonly as the consequence of operational short-term solutions to pressing problems. The CERC crisis at Fort Belvoir evolved from the fact that three of the four actors—the Office of Chief of Engineers, the Wave Dynamics Division at the Waterways Experiment Station, and the Directorate of Research and Development—came to pursue new objectives while CERC held fast to an older course.

The Coastal Engineering Research Center was created at a moment when Federal policies favored Corps programs, and CERC's ideas and plans were well received for a decade thereafter. The CERC staff naturally came to view the salubrious Corps climate of the early 1960s as a permanent environment. But as early as 1965, when OCE began fashioning new budget systems and procedures, CERC's organizational environment was changing. Because its managers and staff did not pay close attention to the larger organization within which the Center worked, CERC slowly drifted from the mainstream of Corps thinking.

The ability of CERC to conduct basic research was always the major source of its organizational strength. While it was both the Corps' lead agency and at the forefront of coastal engineering research, CERC was able to nurture its unusually independent existence inside the Corps.

In this context and with the endorsement of the Coastal Engineering Research Board, CERC's decision to focus on data collection and laboratory and modeling experiments to search for applicable general theories was critical. Establishing the basic research focus meant telling researchers what problems CERC and the Corps considered important and how to approach them. In time, these researchers discovered new and interesting questions and looked for answers within their operational framework. While much good work came out of their programs, CERC researchers failed to achieve the meld of theoretical and applied research leading to a handy general reference to provide the Corps' customer with answers to specific problems.

Fatefully, CERC's focus on data collection caused researchers there to overlook the possibilities implicit in the new methodologies that the Wave Dynamics Division was able to exploit. When WDD responded to the request from the North Central District for a study of the wave climate on the Great Lakes, the way was open for WES to develop research capabilities that paralleled those at CERC.

No long-range planning process in the early 1960s could have anticipated the Federal budget problems of the late 1970s. The sudden and sharp reductions in the Corps' research budget that required DORD to make deep cuts originated outside the Corps. At the same time, CERC found it had shaped itself to the designs of 1963 too well. In providing expertise for many innovative undertakings, CERC offered the Corps technical guidance and support at a senior level. The Center could do the specialized research that was not a part of the Corps overall research development program but was nonetheless important. However, CERC could not reemerge as the center of expertise in coastal engineering until basic and costly equipment needs were met.

When hard choices had to be made, the Corps elected to relocate CERC, that is, to move the organization from Fort Belvoir to Vicksburg. However, if the essence of an organization is its people, this is not what happened. An overwhelming number of CERC's people elected not to transfer. By December 1983, when 105 of the 134 personnel spaces had been filled, CERC consisted of 20 people who had moved to Vicksburg; 14 people at the Duck,

North Carolina, Field Research Facility; 42 people at the Waterways Experiment Station who transferred from the Wave Dynamics Division to CERC; and 58 new hires. The old Center had ceased to exist. As DORD and OCE desired, a new CERC had been created.

NOTES

Chapter I

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52. U.S. Congress, House, Committee on Public Works, *Insurance and Other Programs for Financial Assistance to Flood Victims. A Report from the Secretary of the Department of Housing and Urban Development to the President, as Required by the Southeast Hurricane Disaster Relief Act of 1965 (Public Law 89-339, 89th Congress, H.R. 11539, November 8, 1965)*, 89th Cong., 2d sess., Committee on Public Works, Committee Print No. 49, pp. 40-41; P.L. 1016, 84th Cong., 1965, 70 Stat. 1078.

53. U.S. Congress, Senate, Committee on Public Works, *A Program for Reducing the National Flood Damage Potential, Memorandum of the Chairman to Members of the Committee on Public Works, United States Senate*, 31 Aug. 1959, 86th Cong., 1st sess.

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56. P.L. 874, 87th Congress, H.R. 13273, approved 23 October 1962, 76 Stat. 1178, 33 U.S.C. 426g.

57. Corps of Engineers Research in Coastal Engineering, unsigned memoranda, 20 Aug. 1969, Files, MSG, CERC.

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59. Department of the Army, Corps of Engineers, *CERC Bulletin and Summary Report of Research Progress For Fiscal Year 1964*, Vol. I, CERC, p.2; U.S. Congress, Senate, Committee on Public Works, *Making Certain Changes in the Functions of the Beach Erosion Board and the Board of Engineers for Rivers and Harbors*, S. Rpt. 271, to accompany S. 1523, 88th Cong., 1st sess., 19 June 1963.

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1. U.S. Congress, Senate, Committee on Public Works, *Making Certain Changes in the Functions of the Beach Erosion Board and the Board of Engineers for Rivers and Harbors*, pp. 5-8; ER 10-1-16, Organization and Functions, U.S. Army Coastal Engineering Research Board, 18 Nov. 1963.

2. ER 10-1-16; Research Responsibilities of the Coastal Engineering Research Center, 30 Oct. 1963, with attachments, RG 77, Box 69, WNRC, Suitland, MD.

3. Minutes of the Second CERB Meeting, 4-7 Aug. 1964, p. 12, Files, MSG, CERC.

4. Interview with Thorndike Saville, Jr., 15 July 1985.

5. "Research Responsibilities of the Coastal Engineering Research Center," 30 Oct. 1963, with attachments, RG 77, Box 69, WNRC, Suitland, MD.

6. Briefing for General Wilson on Coastal Engineering Research Center and Board, 10:30 AM, 17 Feb. 1964, Files, MSG, CERC; Research Respon-

sibilities of the Coastal Engineering Research Center, 30 Oct. 63, with attachments, RG 77, Box 69, WNRC, Suitland, MD.

7. Memorandum, Maj. Gen. Ernest Graves, President, CERB, to Chief of Engineers, 2 Nov. 1976; Col. F.O. Diercks, Director, CERC, Evaluation of Civil Works Research Benefits, 24 May 1965, RG 77, Box 70, File: Evaluation of CW Research Benefits, WNRC, Suitland, MD.

8. Col. R.J.B. Page, Civil Works Directorate, to Col. F.O. Diercks, Director, CERC, 22 Apr. 1965, and reply, Evaluation of CW Research Benefits, 24 May 1965, RG 77, Box 70, File: Coastal Engineering Research Benefits, WNRC, Suitland, MD.

9. The study areas were wave mechanics; currents; shore processes; sound, bay, lake lagoon, and estuary processes; inlet processes; and sediments. CERC had acquired primary responsibility in the engineering design areas related to beach stability, recreation beaches; bypassing systems; tidal inlet design; open ports and anchorages; storm protection; underwater installations, offshore islands, breakwaters, and causeways; miscellaneous structures; and platforms and towers.

10. Options Paper, "Coastal Engineering Research," 20 Apr. 1981, Office of the Director, DORD, OCE.

11. Lt. Col. Edward M. Willis, Director, Corps of Engineers Research and Investigation Programs, to Chief of Engineers, 4 Dec. 1969, RG 77, Box 4, File: Corps of Engineers Research and Investigation Programs, WNRC, Suitland, MD.

12. Brig. Gen. John A.B. Dillard, South Pacific Division Engineer, to Brig. Gen. H.G. Woodbury, Jr., Director of Civil Works, 5 June 1967, and reply 15 Aug. 1967, RG 77, Box 8, File: CERC Activities, WNRC, Suitland, MD.

13. P.L. 89-454, 89th Congress, S. 944, 17 June 1966, 80 Stat. 203, 204; the President's Message to the Congress Transmitting His Second Annual Report on Marine Resources and Engineering Development, 11 Mar. 1968, reprint, Folder Marine Council, Thorndike Saville, Jr., Papers.

14. Joseph M. Caldwell, Acting Director, CERC, to Chief of Engineers, 23 Feb. 68, Long-Range Research and Development Program in Coastal Engineering, Folder, Master Plan; Coastal Engineering, Lead Agency Role of the Corps of Engineers, CERC FY 69 Budget Questions, Folder, Reproducible Copies 1964, Thorndike Saville, Jr., Papers.

15. Beach Erosion Board, Summary Tabulation, Tentative Five-Year Research Program, 21 Mar. 1963, BEB, Corps of Engineers; Ten-Year Program in Research in Marine Sciences, 8 Aug. 1961, Folder, Reproducible Copies 1964, Thorndike Saville, Jr., Papers.

16. CERC Long Range Organization Plan (FY 1966 - FY 1975), 30 Dec. 1965, CERC Research and Development Program, 2 Apr. 1964, revision of 10 Dec. 1964; CERC, Coastal Engineering Research and Development Program of CERC, 26 June 1964, Folder, Reproducible Copies 1964, Thorndike Saville, Jr., Papers.

17. Minutes of the Second CERB Meeting, 4-7 Aug. 1964; Minutes of 4th CERB Meeting, Files, MSG, CERC, pp. 12-13.

18. Special Order No. 72, Office of Chief of Engineers, 18 Sept. 1930; *Minutes of SPB and BEB Meetings 1930 through 1946*, CERC Library, WES.

19. P.L. 520, 71st Cong., approved 3 July 1930, 46 Stat. 945, 33 U.S.C. 426.

20. Statement of Dean O'Brien, Official Report of Proceedings Before the U.S. Army Corps of Engineers in the Matter of the Executive Session of the 19th CERB Meeting, 19 Oct. 1972, pp. 44-45. Forty years later, O'Brien noted, "We still don't understand the shore of Long Island" (p. 52).

21. CERC FY 69 Budget Questions, Folder, Reproducible Copies 1964; Proposed Five Year Plan, Coastal Engineering and Development Program (CERC Only), Folder, Reproducible Copies 1964, Thorndike Saville, Jr., Papers.

22. [CERC] Stationing Requirement, n.d., File: Stationing Requirement, 4 Oct. 1970, RG 77, Box 1, WNRC; Corps of Engineers Research in Coastal Engineering; Unsigned memorandum, 20 Aug. 1969, Files, MSG, CERC; interview with Kathryn Rees, 30 July 1985. Rees joined the Beach Erosion Board in 1959 and by 1963 was secretary to both the CERC commander and the technical director.

23. CERC FY 69 Budget Questions, Folder, Reproducible Copies 1964, Thorndike Saville, Jr., Papers. Unsuccessful bulkhead and groin beach protection projects had been constructed at Cape

May, NJ, and at Palm Beach and Miami, FL, but these had been built by local interests. The original Port Mansfield, TX, jetties, designed and constructed locally, also had failed. At the request of local interests and as authorized by Congress, the Corps took over the project and constructed new jetties, which worked. Well-known major failures abroad included the Lexios Harbor breakwater in Portugal.

24. Coastal Engineering Research Benefits, 26 Nov. 1965, RG 77, Box 70, File: Coastal Engineering Research Benefits, WNRC, Suitland, MD.

25. Minutes of the Third CERB Meeting, 1-3 Dec. 1964, Files, MSG, CERC, p. 12.

26. Interview with Thorndike Saville, Jr., 15 July 1985; Comments of Thorndike Saville, Jr., Official Report of Proceedings Before the U.S. Army Corps of Engineers in the Matter of the Executive Session of the 19th CERB Board Meeting, 19 Oct. 1972, pp. 59-60, Files, MSG, CERC; U.S. Army Corps of Engineers, CERC. Statement of Mission and Functions, Jan. 1980, CERC Boxed Records; Department of the Army, Corps of Engineers Ten Year Program in Oceanography FY 1963 - FY 1973, 25 Sept. 1961, p. 4, Folder, 10-Year Program, Thorndike Saville, Jr., Papers.

27. Draft memorandum, 20 Mar. 1975, Thorndike Saville, Jr., Papers. The Office of Naval Research reference is to the 10 May 1974 revision of ER 10-1-9.

28. Minutes of the 3d CERB Meeting, 1-3 Dec. 1964, Attachment 2, Files, MSG, CERC; Abstract of Presentation *History of CTH* by J.B. Lockett, Recorder, Joint Meeting, Committee on Tidal Hydraulics (CTH), Coastal Engineering Research Board (CERB), 13-15 Oct. 1971, appendix; Minutes of the 3d CERB Meeting, 1-3 Dec. 1964, Attachment 2, Files, MSG, CERC. The publication referenced was Committee Report No. 1, Feb. 1950, "Present State of Knowledge of Factors Affecting Tidal Hydraulics and Related Matters."

29. Minutes of the 3d CERB Meeting, 1-3 Dec. 1964, pp. 4-6 and Attachment 1, Files, MSG, CERC.

30. Interview with Claude E. Chatham, Chief, Wave Dynamics Branch, CERC, 21 Aug. 1986.

31. Minutes of the 3d CERB Meeting, 1-3 Dec. 1964, Attachment 2, Files, MSG, CERC; Abstract of Presentation *History of CTH* by J.B. Lockett, Recorder, Joint Meeting, Committee on Tidal Hydraulics (CTH), Coastal Engineering Research Board (CERB), 13-15 Oct. 1971, appendix.

32. Minutes of the 3d CERB Meeting, 1-3 Dec. 1964, pp. 4-6, and Attachment 2, Files, MSG, CERC. Test models were the Delaware River Model, Savannah Harbor, Charleston Harbor, Narragansett Bay, New York Harbor, Galveston Harbor, and the Houston Ship Channel.

33. Minutes of the 3d CERB Meeting, 1-3 Dec. 1964, pp. 4-6, and Attachment 2, Files, MSG, CERC.

34. Minutes of the 8th CERB Meeting, 23-25 May 1967, Executive Session, Files, MSG, CERC.

35. Minutes of the 10th CERB Meeting, 1-3 May 1968, p. 3, Files, MSG, CERC; Coastal Engineering Research Benefits, 26 Nov. 1965, RG 77, Box 70, File: Coastal Engineering Research Benefits, WNRC, Suitland, MD.

36. Lt. Col. Guy E. Jester, Acting Director, WES, to Chief of Engineers, 28 Feb. 1966, Civil Works Investigations Programming - FY 1968.

37. Interview with Claude E. Chatham, Chief, Wave Dynamics Branch, CERC, 21 Aug. 1986; interview with Rudolph P. Savage, 17 July 1985.

38. S. Rpt. 1079 to H.R. 8918, 85th Cong., 21 Aug. 1957, attached to Col. Allen A. Gutral, Executive, BEB, to Maj. Gen. Charles G. Holle, President, BEB, 29 Oct. 1957, RG 77, Box 34, File: New Building, WNRC, Suitland, MD.

39. L.L. Watkins, Engineer, Design Branch, to Donald S. Wakefield, Tennessee Technological University, 20 Jan. 1967, RG 77, Box 8, File: Wave Generator; Col. F[rederick] O. Diercks, Director, CERC, Proposed OCE Reply to CERC DF, "Construction of Shelter for Shore Processes Test Basin," dated 31 Aug 1964 and 21 Jan. 1965, RG 77, Box 34, File: New Building, WNRC, Suitland, MD.

40. O.W. Bailey, Chief, Planning Section, Engineering Services Branch, Washington Aqueduct Division, Memorandum for the Record, conference relative to the site of proposed construction for the Board of Engineers for Rivers and Harbors, 9 Sept. 1963, RG 77, Box 34, File: New Building, WNRC, Suitland, MD.

41. Col. Roy S. Kelly, Baltimore District Engineer, to Chief of Engineers, 2 Mar. 1964, Dalecarlia Reservation, RG 77, Box 34, File: New Building, WNRC, Suitland, MD.

42. Col. F[rederick] O. Diercks, Director, CERC, Proposed OCE Reply to CERC DF, "Construction of Shelter for Shore Processes Test Basin," dated 31 Aug 1964, 21 Jan. 1965, RG 77, Box 34, File: New Building, WNRC, Suitland, MD.

43. Caldwell to Chief of Engineers, Considerations in Possible Relocation of CERC, 23 Feb. 1968, RG 77, Box 34, File: New Building, WNRC, Suitland, MD.

44. Lt. Col. Myron Dow Smoke, Executive Secretary, CERB, Memorandum for President and Members, CERB, Summarized Status Report on Proposed CERC Facilities at Fort Belvoir, VA, 11 Oct. 1968, RG 77 Box 34, File: New Building, WNRC, Suitland, MD.

45. W.H. Tamm, Assistant Chief, Engineering Division, File Memorandum, Conference Concerning Redesign of Kingman Building for Siting at Fort Belvoir, VA, RG 77, Box 34, File: New Building, WNRC; Minutes, 18th CERB Meeting, 18-20 Apr. 1972, pp. 4-5, Files, MSG, CERC.

46. Interview with Thorndike Saville, Jr., 15 July 1985; *The Quarterly CERCular*, Vol. 2, No. 1, Oct. 1976; Col. Ted Bishop, Commander, CERC, Memorandum for Director, Research and Development, Proposed Move Coastal Engineering to WES, 4 Dec. 1981, DRD, OCE, Notebook: CERC Move, Vol. I; Minutes, 18th CERB Meeting, 18-20 Apr. 1972, pp. 4-5, Files, MSG, CERC; Thorndike Saville, Jr., Memorandum to Director, Major Requirements for the Projected Move to Fort Belvoir Involving Immediate Replacement of Present Facilities and/or Necessary Plans for Their Better and More Efficient Operation, CERC Boxed Records; interview with Rudolph P. Savage, 17 July 1985.

47. Interview with Rudolph P. Savage, 17 July 1985; *Army Research and Development News Magazine*, Sept.-Oct. 1975, p. 6.

48. Col. James L. Trayers to Gribble, 12 Aug. 1975, Thorndike Saville, Jr., Papers. Gribble's address was drafted at CERC.

49. Myron Dow Smoke, Memorandum to the Director [CERC], Summarized Status Report on Proposed CERC Facilities at Fort Belvoir, VA, 11 Oct. 1968, RG 77 Box 34, File: New Building, WNRC; interview with Rudolph P. Savage, 17 July 1985.

50. Interview with Rudolph P Savage, 17 July 1985; *The Quarterly CERCular*, Vol. 4, No. 3., July 1979; Vol. 5, No. 4, Oct. 1980.

51. Interview with Rudolph P. Savage, 17 July 1985; *The Quarterly CERCular*, Vol. 4, No. 3., July 1979; Vol. 5, No. 4, Oct. 1980.

52. *The Quarterly CERCular*, Vol. 2, No. 2, Jan. 1977; Vol. 4, No. 3, July 1979; *The CERCular*, Vol. CERC-85-1, Mar. 1985.

53. Minutes of the 1st CERB Meeting, 13-14 Apr. 1964, p. 3, Files, MSG, CERC.

54. Minutes of the Second CERB Meeting, 4-7 Aug. 1964, pp. 11-12, Files, MSG, CERC.

55. Memorandum, Thorndike Saville, Jr., to Mr. Caldwell, Review of CERC Organization, 28 Aug. 1964, CERC Boxed Records.

56. Minutes of the 8th CERB Meeting, 23-25 May 1967, Files, MSG, CERC.

57. Minutes of the 10th CERB Meeting, 1-3 May 1968, p. 4, Files, MSG, CERC.

58. Interview with Kathryn Rees, 30 July 1985.

59. *Ibid.* The Washington *Post*, 24 Dec. 1980; *The Quarterly CERCular*, Vol. 6, No. 1, Jan. 1981. Retired in 1973 after 40 years of Federal service, Caldwell was twice awarded the Department of the Army Meritorious Civilian Service Award, in 1962, for the design for the emergency hurricane protection, and in 1973, upon his retirement, for his supervision of engineering and design of the Corps' Civil Works programs. Caldwell also served as the U.S. Chairman of the U.S.-Canadian Columbia River Treaty and received the Southeast Asia Award from the Navy for onsite support of port development in Vietnam in 1965.

60. Caldwell, Staffing of Wave Tank Facilities, 21 May 1969; Lt. Col. Edward M. Willis, CERC Director, to Chief of Engineers, Corps of Engineers Research and Investigation Programs, 4 Dec. 1969, RG 77, Box 34, File: New Building, WNRC; interview with Rudolph P. Savage, 17 July 1985; interview with Bennie Maddox, 16 July 1985.

61. Interview with Thorndike Saville, Jr., 15 July 1985; *The Quarterly CERCular*, Vol. 6, No. 1, Jan. 1981; Vol. 4, No. 4, Oct. 1979. Saville served as Assistant Chief and then Chief of the Research Division from 1958 to 1960. He retired on 17 Jan.

1981, after more than 33 years of Federal service, but was retained in a retired-annuitant status to assist the Commander and Director until July 1981. He earned the 1979 John G. Moffatt-Frank E. Nichol Harbor and Coastal Engineering Award for his wave runup studies that led to advances in the design and construction of harbor and coastal works and for his leadership of the Coastal Engineering Research Center.

62. Joseph M. Caldwell, Acting Director, CERC, to Chief of Engineers, 14 July 1967, Provision of PPBS Material, Thorndike Saville, Jr., Papers.

Chapter III

1. Edward F. Thompson, "Results from the CERC Wave Measurement Program," *Proceedings of the International Symposium on Ocean Wave Measurement and Analysis, ASCE/New Orleans, La., September 9-11, 1974*, pp. 836-855; J. Richard Weggel, "Maximum Breaker Height," *Journal of the Waterways, Harbors and Coastal Engineering Division, Proceedings of the American Society of Civil Engineers* 98 (Nov. 1972):529-548.

2. David B. Duane, D. Lee Harris, Richard O. Bruno, and Edward B. Hands, "A Primer of Basic Concepts of Lakeshore Processes," CERC Miscellaneous Paper No. 1-75, Jan. 1975.

3. Joseph M. Caldwell, "The Research Program of the Coastal Engineering Research Center," *Shore and Beach*, Apr. 1968, pp. 17-19, offprint, Files, MSG, CERC; Minutes of the 1st Meeting Coastal Engineering Research Board, 13-14 Apr. 1964, p. 2, Files, MSG, CERC; Weggel, "Maximum Breaker Height," pp. 529-548; Thompson, "Results from the CERC Wave Measurement Program," pp. 836-855.

4. Interview with Rudolph P. Savage, 17 July 1985. Based on their studies, CERC researchers concluded that the principles related to wave action phenomena on the Great Lakes and oceans were the same; any differences could be attributed to the different densities of water.

5. Interview with Rudolph P. Savage, 17 July 1985.

6. *Ibid.*

7. U.S. Congress, House, *Beach Erosion Study, St. Simons Island, GA*, H. Doc. 820, pp. 7-8; "Report on St. Simons Island Studies," pp. 18-23.

8. H. Doc. 169; U.S. Congress, House, *Beach Erosion at Hollywood Beach, Fla.*, H. Doc. 253, 75th Cong., 1st sess., 20 May 1937.

9. U.S. Congress, House, *Palm Beach, Fla. Beach Erosion Study*, H. Doc. 772, 80th Cong., 2d sess., 1948.

10. E.E. Gesler, "What to Expect from a Beach Erosion Study," pp. 16-19.

11. Clark et al., *Coastal Environmental Management Guidelines*, pp. 91-94, 97; D. E. Newman, "Beach Replenishment: Sea Defenses and a Review of the Role of Artificial Beach Replenishment," *Proceedings Institution of Civil Engineers*, 60, Part I (Aug., 1976):445-460.

12. H. Doc. 682, *Harrison County, Miss., Beach Erosion Control Study*.

13. Col. Walter K. Wilson, Jr., "Beach Erosion Problems in the Mobile District," pp. 8-10; Francis F. Escoffier, "Coastal Problems in the Mobile District," *Shore and Beach* XXIV (April 1956):16-19; Francis P. Koisch, "A Half Century of Coastal Conservation," *Shore and Beach* 37 (April 1969):47-48, 54.

14. Minutes of the 102d Meeting of the Beach Erosion Board, 4 Nov. 1954; Minutes of the Beach Erosion Board 1947 to 1963, WES Library.

15. P.L. 826, 84th Cong., 70 Stat. 702, 33 U.S.C. 426e.

16. S. Jeffress Williams and David B. Duane, "Geomorphology and Sediments of the Inner New York Bight Continental Shelf," *CERC Technical Memorandum No. 45*, July 1974.

17. Minutes, CMREF Research Panel, 11 Dec. 1967; Minutes of the 1st Meeting Coastal Engineering Research Board, 13-14 Apr. 1964, p. 3, Files, MSG, CERC; "Oceanographic Research and Development in the Federal Government," A Compendium, Draft, ICO Publication No. 19, CERC

Boxed Records, pp. 21, 31, 39-40, 156-157, 158-159, 161-165.

18. Duane, et al., "A Primer of Basic Concepts of Lakeshore Processes."

19. *Ibid.* The situation is loosely analogous to the indeterminacy principle that German physicist Werner Heisenberg arrived at in 1927: one can learn either the exact position of a given particle or its exact trajectory, but not both.

20. Minutes of the Second Meeting of the Coastal Engineering Research Board, 4-7 Aug. 1964, pp. 12-13, Files, MSG, CERC.

21. Corps of Engineers Research in Coastal Engineering. Unsigned memorandum, 20 Aug. 1969, Files, MSG, CERC. The research categories were: (a) Wave Action in Coastal Waters, (b) Shore Processes, (c) Tides and Surges, (d) Inlet Dynamics, (e) Estuary Dynamics, (f) Coastal Works Evaluation, (g) Functional Design of Coastal Works, (h) Structural Design of Coastal Works, (i) Coastal Construction Techniques, (j) Environmental Data Collection.

22. Thorndike Saville, Jr., J. Richard Weggel, and Lt. Cdr. Kenneth Fusch, Civil Engineer Corps, USN, "The Coastal Engineering Research Center," *The Military Engineer* 434 (Nov.-Dec. 1974):368-371; Minutes of the 3d Meeting of the Coastal Engineering Research Board, 1-3 December 1964, Files, MSG, CERC.

23. Minutes of the 5th Meeting of the Coastal Engineering Research Board, 5-7 October 1965, Files, MSG, CERC; interview with Rudolph P. Savage, 17 July 1985.

24. U.S. Congress, House, *Wrightsville Beach, N.C.*, H. Doc. 218, 73rd Cong., 3d sess., 12 Jan. 1934, p. 4.; U.S. Congress, House, *Beach Erosion at Kitty Hawk, Nags Head, and Oregon Inlet, N.C.*, H. Doc. 155, 74th Cong., 1st sess., 17 Apr. 1935.

25. H. Doc. 253.

26. U.S. Congress, House, *Beach-Erosion Study at Blind Pass, Fla.*, H. Doc. 187, 75th Cong., 1st sess., 30 Mar. 1937, pp. 6-7.

27. U.S. Congress, House, *Beach Erosion at Daytona Beach, Fla.*, H. Doc. 571, 75th Cong., 2d sess., 6 Apr. 1938, p. 31.

28. U. S. Congress, House, *Beach Erosion at Folly Beach, S.C.*, H. Doc. 156, 74th Cong., 1st sess., 17 Apr. 1935, pp. 5-12.

29. H. Doc. 820, pp. 7-8.

30. Saville, "Future Federal Policy in Coastal Erosion?"

31. Harold G. Peacock, "CERC Field Wave Gaging Program," *Proceedings of the International Symposium on Ocean Wave Measurement and Analysis, American Society of Civil Engineers, New Orleans, La., September 9-11, 1974*, pp. 20ff.

32. *Ibid.*

33. Minutes of the Second Meeting of the Coastal Engineering Research Board, 4-7 Aug. 1964, p. 2; Minutes of the 6th Meeting of the Coastal Engineering Research Board, 23-24 May 1966, p. 3; Minutes of the 8th Meeting of the Coastal Engineering Research Board, 23-25 May 1967, pp. 4-5, 21-23; Files, MSG, CERC; interview with Thorndike Saville, Jr., 15 July 1985.

34. John M. Darling, "Surf Observations Along the United States Coasts," *Journal of the Waterways and Harbors Division, Proceedings of the American Society of Civil Engineers* (Feb. 1968):11-21; Joseph M. Caldwell, "Coastal Processes and Beach Erosion," *Journal of the Society of Civil Engineers* 53 (Apr. 1956):142-157; David B. Duane, "Synoptic Observations of Sand Movement," *Proceedings of the 12th Coastal Engineering Conference, September 1970, Washington, D.C.*, pp. 799-813; Craig H. Everts, Allen E. DeWall, and Martin T. Czerniak, "Behavior of Beach Fill at Atlantic City, New Jersey," *Proceedings of the Coastal Engineering Conference (14th), Copenhagen (Denmark), Jun. 1974*, pp. 1370-1388; Minutes of the 24th Meeting of the Coastal Engineering Research Board, 30 Jun.-2 July 1975, p. 4, Files, MSG, CERC.

35. Col. F.O. Diercks, Director, CERC, "Evaluation of Civil Works Research Benefits," 24 May 1965, CERC Boxed Records.

36. Minutes of the 28th Meeting of the Coastal Engineering Research Board, 28-30 Jun. 1977, pp. 7-9; Transcript of Meeting of the Coastal Engineering Research Board, May 4 1976, pp. 2-3 2-7; Transcript of Proceedings, Meeting of the Coastal Engineering Research Board, 14 Nov. 1980, p. 49, Files, MSG, CERC.

37. Minutes of the 12th Meeting of the Coastal Engineering Research Board, 8-10 July 1969, Appendix; Minutes of the 8th Meeting of the Coastal Engineering Research Board, 23-25 May 1967, pp. 4-5, Files, MSG, CERC; Dennis W. Berg, "Systematic Collection of Beach Data," *Proceedings of the Eleventh Conference on Coastal Engineering, London, England, September 1968*, sponsored jointly by the Institution of Civil Engineers and the American Society of Civil Engineers (Sept. 1969), pp. 273-297; Dennis W. Berg and Eugene F. Hawley, "TimeInterval Photography of Littoral Phenomena," *Proceedings of the 13th Coastal Engineering Conference, July 10-14, 1972, Vancouver, B.C. Canada* (July 1973), pp. 725-745; Richard O. Bruno and Larry W. Hipakka, "Littoral Environment Observation Program in the State of Michigan," CERC Research Report R 4-74, 1974, WES Library; William R. James and Robert J. Hallermeier, "Nearshore Wave Direction Gage," *Journal of the Waterways, Harbors and Coastal Engineering Division, American Society of Civil Engineers* 102 (Nov. 1976):379-393.

38. George Kalkanis, *Transportation of Bed Material Due to Wave Action*, CERC Technical Memorandum No. 2, Feb. 1964; J.C. Fairchild, "A Tractor-Mounted Suspended Sand Sampler," *Shore and Beach* 33 (Oct. 1965):4; M.M. Das, *Suspended Sediment and Longshore Sediment Transport Data Review*, (Fort Belvoir, VA: CERC, July 1973).

39. H.R. Brashear, et. al., "Processing and Analysis of Radioisotopic Sand Tracer (RIST) Study Data," *Proceedings of the Twelfth Coastal Engineering Conference, September, 1970, Washington, D.C.*, pp. 821-830; William R. James, "A Class of Probability Models for Littoral Drift," *Proceedings of the Twelfth Coastal Engineering Conference, September, 1970, Washington, D.C.*, pp. 831-837; Minutes of the 8th Meeting of the Coastal Engineering Research Board, 23-25 May 1967, pp. 18-20; David B. Duane, "Review of RIST Program (Including the March 1971 Test at Masonboro Inlet)," CERB Meeting at WES, Apr. 1971, Files, MSG, CERC.

40. Minutes of the 23rd Coastal Engineering Research Board Meeting, 23-25 September 1974, Enclosure 8, Coastal Field Data Collection, Files, MSG, CERC.

41. Interview with Thorndike Saville, Jr., 15 July 1985.

42. *Ibid.*

43. *The Quarterly CERCular*, Vol. 5, No. 2, Apr. 1980.

44. Caldwell, "Coastal Processes and Beach Erosion"; Fairchild, "A Tractor-Mounted Suspended Sand Sampler," p. 4.

45. Duane, "Synoptic Observations of Sand Movement," pp. 799-813; Brashear, et al., "Processing and Analysis of Radioisotopic Sand Tracer (RIST) Study Data," pp. 821-830.

46. James, "A Class of Probability Models for Littoral Drift," pp. 831-837.

47. Craig H. Everts, *Sedimentation in a Half-Tide Harbor* (Fort Belvoir, VA: CERC, Feb. 1977); Das, *Suspended Sediment and Longshore Sediment Transport Data Review*.

48. Transcript of the Meeting of the Coastal Engineering Research Board, 4 May 1976, pp. 2-61 - 2-66, Files, MSG, CERC.

49. Quinn, *The History of the Beach Erosion Board*, pp. 51-68.

50. L.L. Watkins, Engineer, Design Branch, to Donald S. Wakefield, Tennessee Technological University, 20 Jan. 1967, RE 77, Box 8, File, Wave Generator, WRNC, Suitland, MD.

51. *The Quarterly CERCular*, Vol. 2, No. 4, July 1977. The depreciated value of the SPTB facility in 1983 was $1.14 million.

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Chapter V

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Savage, former Chief, Research Division, CERC, 17 Jul. 1985.

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32. Transcript of CERB Meeting, Wednesday, 30 Apr. 1980, pp. 79-92; transcript of CERB Meeting, Monday, 3 May 1976, pp. 1-124 to 1-127, Files, MSG, CERC.

33. Transcript of CERB Meeting, Wednesday, 30 Apr. 1980, pp. 79-92; transcript of CERB Meeting, Monday, 3 May 1976, pp. 1-124 to 1-127, Files, MSG, CERC.

34. Transcript of CERB Meeting, Wednesday, 30 Apr. 1980, pp. 79-92, Files, MSG, CERC. The observed water level was 580.51 feet, less than the design water level of 582.92 feet; the actual wind was 17 miles an hour with gusts to 29 mph, far under the designed 45 mph; and the actual wave, as near as observers could calculate, was less than the design 5.7 feet. Design runup calculations were 4.85 feet; observed runup was seven feet.

35. Brig. Gen. Robert L. Moore and Donald T. Resio, Wave Information Program in the Great Lakes, transcript of the 25th Meeting of the U.S. Army Corps of Engineers Coastal Engineering Research Board, 4 Dec. 1975, pp. 74-77; Transcript of Coastal Engineering Research Board Meeting, Wednesday, 30 Apr. 1980, pp. 79-92, MSG Files, CERC.

36. Interviews with Robert W. Whalin, 18 and 22 Aug. 1986; interview with C. Linwood Vincent, Chief, Coastal Process Branch, CERC, 19 Aug. 1986; interview with Donald T. Resio, President, Offshore and Coastal Technologies, 20 Aug. 1986.

37. Donald T. Resio and C. Linwood Vinvent, "A Numerical Hindcast Model for Wave Spectra on Water Bodies with Irregular Shoreline Geometry; Report 2, Model Verification with Observed Wave Data," Hydraulics Laboratory, WES, Dec. 1978, p. 1; Brig. Gen. Robert L. Moore and Donald T. Resio, Wave Information Program in the Great Lakes, transcript of the 25th Meeting of the U.S. Army Corps of Engineers Coastal Engineering Research Board, 4 Dec. 1975, pp. 74- 77, MSG Files, CERC.

38. Donald T. Resio and Charles L. Vincent, "Design Wave Information for the Great Lakes; Report 1, Lake Erie," Jan. 1976, WES Technical Report No. H-76-1, Vicksburg, MS, pp. 4, 9-10.

39. Brig. Gen. Robert L. Moore and Donald T. Resio, Wave Information Program in the Great Lakes, transcript of the 25th Meeting of the U.S. Army Corps of Engineers Coastal Engineering Research Board, 4 Dec. 1975, pp. 77-92, MSG Files, CERC.

40. The numerical model originally was programmed and tested in the CROSS operating system unique to the Los Alamos Scientific Laboratory. The model later was adjusted to run on two different CDC 7600 computers with a SCOPE operating system. Initially developed for Lakes Erie and Ontario, the model was modified to economize data storage for the larger lakes, particularly after the changeover to the SCOPE operating system, because the core memory requirement for Lake Superior of

272,000 words was close to the capacity of the CDC 7600. Resio and Vincent, "A Numerical Hindcast Model for Wave Spectra," p. 47 .

41. Interview with Donald T. Resio, 20 Aug. 1986; interview with C. Linwood Vincent, 19 Aug. 1986.

42. Donald T. Resio and Charles L. Vincent, "Design Wave Information for the Great Lakes; Report 2, Lake Ontario," Mar. 1976, WES Technical Report No. H-76-1, Vicksburg, MS, p. 11; Donald T. Resio and Charles L. Vincent, "Estimation of Winds over the Great Lakes," 1976, Miscellaneous Paper H-76-12, Hydraulics Laboratory, WES, Vicksburg, MS, pp. 48-49. The theoretical results provided a basis for comparing empirical data sets and aided in establishing a rational means of examining systematic variations. Good agreement between theory and observation indicated that wind estimates over a lake for a wide range of synoptic conditions could be made with a root mean square error of under five knots windspeed and offered relatively good accuracy in extreme wind conditions where there were little or no direct measurements of winds over the lake.

43. Transcript, U.S. Army Coastal Engineering Research Board, CERB Meeting, Monday, 3 May 1976, pp. 1-123 to 1-129; transcript, CERB Meeting, 23 Oct. 1978, pp. 99-100, MSG Files, CERC.

44. Resio and Vincent, "A Numerical Hindcast Model for Wave Spectra," pp. 4-6, 49-52.

45. Interview with C. Linwood Vincent, 19 August 1986; Resio and Vincent, "Design Wave Information for the Great Lakes; Report 1, Lake Erie"; Resio and Vincent, "Design Wave Information for the Great Lakes; Report 2, Lake Ontario"; Resio and Vincent, "Design Wave Information for the Great Lakes; Report 3, Lake Michigan," 1976, WES Technical Report No. H-76-1, Vicksburg, MS; Resio and Vincent, "Design Wave Information for the Great Lakes; Report 4, Lake Huron," 1976, WES Technical Report No. H-76-1, Vicksburg, MS; Resio and Vincent, "Design Wave Information for the Great Lakes; Report 5, Lake Superior," 1976, WES Technical Report No. H-76-1, Vicksburg, MS.

46. Resio and Vincent, "Estimation of Winds over the Great Lakes," *Journal of the Waterway, Port, Coastal and Ocean Division, American Society of Civil Engineers*, 103, No. WW2, Proc. Paper 12951 (May 1977):265-283.

47. C.L. Vincent and D.T. Resio, "A Discussion of Wave Prediction in the Northwest Atlantic Ocean," Jacques C.J. Nihoul, *Marine Forecasting, Predictability and Modeling in Ocean Hydrodynamics, Proceedings of the 10th International Liege Colloquium on Ocean Hydrodynamics* (Amsterdam, Oxford, and New York: Elsevier Scientific Publishing Company, 1979), pp. 71-91.

48. Interview with Donald T. Resio, 20 Aug. 1986; interviews with Robert T. Whalin, 18 and 22 Aug. 1986; interview with C. Linwood Vincent, 19 Aug. 1986.

49. Interview with Donald T. Resio, 20 Aug. 1986. Donald T. Resio and Bruce H. Hayden, "An Integrated Model of Storm-Generated Waves," Technical Report No. 8, Department of Environmental Sciences, University of Virginia, Office of Naval Research Geography Programs, Dec. 1973, employed this type of model. It used large-scale atmospheric patterns of surface pressure in defining the conditional probabilities of synoptic events to obtain large-scale climatic trends. The group then converted data from characteristic storm tracks and associated wind fields into a form usable for hindcasting waves and surges. Finally the group employed a breaker-height, surge-height calculation scheme using the data sets to calculate a simulated time-sequence of waves and surges produced by each characteristic storm. The problem in applying the Navy model, Resio and Vincent found, was that wave models could be divided into two classes: parametric and discrete spectral models. Parametric models included techniques where specific parameters of the sea state such as significant wave height or period are predicted from relationships among nondimensional wave characteristics and nondimensional fetch and duration characteristics. Discrete spectral model considered sea state representable by discrete frequency direction bands.

50. Interview with Donald T. Resio, 20 Aug. 1986; interview with C. Linwood Vincent, 19 Aug. 1986.

51. Donald T. Resio and C.L. Vincent, "A Comparison of Various Numerical Wave Prediction Techniques," paper presented at Offshore Technology Conference, Houston, TX, 30 Apr.-3 May 1979, Maritime Technical Society and American Society of Civil Engineers, Paper No. 3642.

52. Donald T. Resio, "The Estimation of Wind-Wave Generation in a Discrete Spectral Model,"

Journal of Physical Oceanography, Vol. 11, No. 4 (Apr. 1981):510-525.

53. Interview with Donald T. Resio, 20 Aug. 1986; Whalin to the author, 12 Jan. 1987.

54. Transcript of the Minutes of CERB Meeting, 23 Oct. 1978, pp. 98-123, Files, MSG, CERC; interview with Donald T. Resio, 20 Aug. 1986; interview with C. Linwood Vincent, 19 Aug. 1986.

55. Donald T. Resio, "Wave Prediction in Shallow Water," paper presented at the 14th Annual Offshore Technology Conference, Houston, TX, May 1982, Paper No. 4242.

56. Researchers had to establish data parameters because no model could handle the full spectrum of information. The magnitude of the number of wave transformations alone ran into the tens of billions of data items. Corps of Engineers' Coastal Field Data Collection Program, presentation by Donald T. Resio, transcript of the Coastal Engineering Research Board Meeting, 14 Nov. 1980, pp. 53-71, Files, MSG, CERC.

57. Corps of Engineers' Coastal Field Data Collection Program, presentation by Donald T. Resio, Transcript of the Coastal Engineering Research Board Meeting, 14 Nov. 1980, pp. 53-71, Files, MSG, CERC.

58. Corps of Engineers' Coastal Field Data Collection Program, presentation by R.P. Savage, Transcript of the Coastal Engineering Research Board Meeting, 14 Nov. 1980, pp. 49-53, Files, MSG, CERC; Summary Minutes of 31st Meeting of the Coastal Engineering Research Board, 2 Jan. 1979, pp. 3-6, Files, MSG, CERC.

59. Corps of Engineers' Coastal Field Data Collection Program, Presentation by R.P. Savage, transcript of the Coastal Engineering Research Board Meeting, 14 Nov. 1980, pp. 49-53; Corps of Engineers' Coastal Field Data Collection Program, presentation by Donald T. Resio, transcript of the Coastal Engineering Research Board Meeting, 14 Nov. 1980, pp. 53-71, transcript of the 40th Meeting of the Coastal Engineering Research Board, 17-20 Oct. 1983, pp. 22-27, Files, MSG, CERC.

60. Transcript of the 40th CERB Meeting, 17-20 Oct. 1983, pp. 22-27, Files, MSG, CERC.

61. E. Bouws, H. Gunther, W. Rosenthal, and C.L. Vincent, "Similarity of the Wind Wave Spectrum in Finite Depth Water," *Journal of Geophysical Research*, Vol. 20, No. C1 (20 Jan. 1985):975-986.

62. C.L. Vincent and D.E. Lichy, "Wave Measurements in ARSLOE, Directional Wave Spectra Applications," *American Society of Civil Engineers* (Sept. 1981), pp. 71-86.

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64. Bouws, et al., "Similarity of the Wind Wave Spectrum in Finite Depth Water," pp. 975-986.

65. E.F. Thompson and C.L. Vincent, "Prediction of Wave Height in Shallow Water," 1983, CERC Report No. R83-14, Fort Belvoir, VA.

66. Robert W. Whalin to the author, 12 Jan. 1987 with enclosures. The study did not end the dispute. Controversy over the project next centered on its economic feasibility.

67. James R. Houston, "Interaction with the Hawaiian Islands Calculated by a Finite-Element Numerical Model," *Journal of Physical Oceanography* 8 (Jan. 1978):93-102; James R. Houston and H. Lee Butler, "A Numerical Model for Tsunami Inundation," 1979, Technical Report HL-79-2, Hydraulics Laboratory, WES Vicksburg, MS.

68. Interview with Bennie Maddox, 16 Jul. 1985; interview with Rudolph Savage, 17 Jul. 1985; interview with Thorndike Saville, Jr., 15 Jul. 1985; interview with Col. Lawrence R. Smith, formerly with the Corps Research and Development Office and in 1979 Inspector General of the Corps, 31 Jul. 1985.

69. Interview with Rudolph P. Savage, 17 Jul. 1985; interview with William E. Roper, Assistant Director, Research and Development, DRD, OCE, 18 Jul. 1985; Col. Ted E. Bishop, CERC, Memorandum for Director, Research and Development, "Proposed Move of Coastal Engineering to WES, 4 Dec. 1981, DRD, OCE, Notebook: CERC Move, Vol. I.

70. Proceedings of the Coastal Engineering Research Board Meeting, 25-26 Apr. 1979 (32d Meeting), Vol. I, p. 195; Summary Minutes of 32d Meeting of the Coastal Engineering Research Board, 29 June 1979, p. 3.

71. Coastal Engineering Research Board Meeting, 12 Nov. 1980, pp. 50-52, Files, MSG, CERC.

Chapter VI

1. Col. Ted Bishop, Commander, CERC, memo slip of 31 Oct. 1979.

2. C.L. Vincent, memorandum for Commander and Director [CERC], "CERC Response to Detroit District on Saginaw Wave Gaging," 25 Oct. 1979, DRD, OCE, Notebook: CERC Move, Vol. I.

3. Cousins, memorandum, "Management of Corps of Engineers Work Related to Coastal and Estuerine Processes, 1 May 1978, DRD, OCE, Notebook: CERC Move, Vol. I.

4. Col. John L. Cannon, Commander, WES, to HQDA, through CERC, 1 June 1978, DRD, OCE, Notebook: CERC Move, Vol. I.

5. Col. John L. Cannon, Commander and Director, WES, "Management of Corps of Engineers Work Related to Coastal and Estuarine Processes," 5 June 1978, DRD, OCE, Notebook: CERC Move, Vol. I.

6. ER 10-1-9, 15 Sept. 1978, DRD, OCE, Notebook: CERC Move, Vol. I.

7. Statement of Maj. Gen. E.R. Heiberg, President CERB, transcript of CERB Meeting, Thursday, 1 May 1980, pp, 199-200, 202; Maj. Gen. Charles I. McGinnis, Outlook in Civil Works, Proceedings of the CERB Meeting, 25-26 Apr. 1979 (32d Meeting), Vol. II, pp. 334-361, Files, MSG, CERC.

8. Official Report of Proceedings before the U.S. Army Corps of Engineers in the Matter of the Executive Session of the 19th CERB Meeting, 9 Oct. 1972, p. 9; Draft Memorandum, 20 Mar. 1975, Thorndike Saville, Jr., Papers; interview with Kathryn Rees, 30 July 1985; interview with Dr. William E. Roper, Assistant Director, Research and Development, DRD, OCE, 18 July 1985; interview with Rudolph P. Savage, 17 July 1985.

9. Minutes of CERB Meeting, May 1976.

10. Maj. Gen. Ernest Graves, President, CERB to Chief of Engineers, 2 Nov. 1976, Files, MSG, CERC.

11. Interview with Col. Lawrence R. Smith, formerly with the Corps' Research and Development Office and in 1979 Inspector Gen. of the Corps, 31 Jul 1985; interview with James Choromokos, Jr., Director, Directorate of Research and Development, OCE, 31 July 1985.

12. Memorandum, Coastal Engineering Research Increase Justification, TS/CERC/11/16/78.

13. Draft memorandum [Col. Ted Bishop, Commander, CERC], 28 Nov. 1980, Thorndike Saville, Jr., Papers.

14. Maj. Gen. Charles I. McGinnis, Outlook in Civil Works, *Proceedings of the CERB Meeting, 25-26 Apr. 1979 (32d Meeting)*, Vol. II, pp. 334-361, Files, MSG, CERC.

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16. Commander Col. Ted Bishop to James Choromokos, Director, Research and Development, Apr. 1980, Thorndike Saville, Jr., Papers.

17. *Thirty-Third CERB Meeting, 25 Sept. 1979*, pp. 218-220 (quote at p. 220); *CERB Meeting, 14 Nov. 1980*, pp. 30-31; *CERB Meeting, 14 Nov. 1980*, pp. 113-120, Files, MSG, CERC.

18. *Thirty-Third CERB Meeting, 25 Sept. 1979*, pp. 218-220 (quote at p. 220); *CERB Meeting,*

14 Nov. 1980, pp. 30-31; *CERB Meeting, 14 Nov. 1980*, pp. 113- 120, Files, MSG, CERC. Interview with Lt. Gen. E. R. Heiberg, Chief of Engineers, 14 Oct. 1986.

19. Memorandum, Shore Protection Pamphlet, 26 Mar. 1980, Folder, Publications, BEB, CERC, Thorndike Saville, Jr., Papers; interview with Thorndike Saville, Jr., 15 July 1985.

20. Bishop to Choromokos, Apr. 1980, Thorndike Saville, Jr., Papers.

21. Interview with Rudolph P. Savage, 17 July 1985; draft memorandum [Col. Ted Bishop, Commander, CERC], 28 Nov. 1980, Thorndike Saville, Jr., Papers.

22. Neill Parker, Reimbursable Support of the Corps, *Proceedings of CERB Meeting, 25-26 Apr. 1979 (32d Meeting)*, Vol. II, pp. 301-307, Files, MSG, CERC.

23. Transcript, *CERB Meeting, 14 Nov. 1980*, pp. 95-113, Files, MSG, CERC.

24. Interview with William E. Roper, 18 Jul. 1985; interview with James Choromokos, Jr., 31 July 1985.

25. Interview with William E. Roper, 18 Jul. 1985.

26. Col. Ted Bishop, Commander, CERC, Memorandum for Director, Research and Development, "Proposed Move Coastal Engineering Center to WES," 4 Dec 1981, DRD, OCE, Notebook: CERC Move, Vol. I; Robert W. Whalin to the author, 16 Jan. 1987.

27. Interview with Col. Lawrence R. Smith, 31 Jul. 1985. Smith had not agreed the decision was correct.

28. James T. McIntyre, Jr., Director, OMB, memorandum for Heads of Executive Departments and Agencies, "Study of Decentralization of Federal Government Functions"; BOB Circular A-60, "Criteria for decentralizing Federal activities from the National Capitol region," 18 July 1963.

29. D.O. Cooke, Deputy Assistant Secretary of Defense, memorandum, "Decentralization of Federal Governmental Functions," 30 May 1979, DRD, OCE, Notebook, CERC Move, Vol. I.

30. Col. Ted. E. Bishop, Commander and Director, CERC, to Col. Max Kovel, Acting Chief, Research and Development Office, OCE, 13 June 1979, DRD, OCE, Notebook: CERC Move, Vol. I.

31. Interview with James Choromokos, Jr., 31 July 1985.

32. *Ibid.*

33. *Ibid.*

34. James Choromokos, Memorandum for Commander and Director, U.S. Army Coastal Engineering Research Center, "Impact of Consolidating Coastal Engineering R&D at WES.[1]

35. Col. Ted Bishop, CERC, memorandum for James Choromokos, Jr., Director, Research and Development, "Impact of Consolidating Coastal Engineering R&D at WES," 17 Mar. 1981, Notebook: CERC Move, Vol. I.

36. Meeting of 18 Apr. 1982, Directorate of Research and Development, Office of Chief of Engineers, Notebook: CERC Move, Vol. I.

37. Options Paper, "Coastal Engineering Research," 20 Apr. 1981, Office of the Director, DRD, OCE.

38. Draft Memorandum, "Possible CERC Move to WES," 2 Dec. 1981.

39. Maj. Gen. E.R. Heiberg, "CERC Move to WES Write-Up," 28 Jan. 1982 (with notation of COE approval 23 Feb. 1982), DRD, OCE, Notebook: CERC Move, Vol. I; interview with James Choromokos, Jr., 31 July 1985.

40. Summary Minutes of 37th CERB Meeting, 20 Jan. 1982, p. 10, Files, MSG, CERC.

41. Fred Camfield, Personal Diary entry of 4 Dec. 1981, copy to the authors, 30 Nov. 1987.

42. Maj. Gen. E.R. Heiberg, "CERC Move to WES Write-Up," 28 Jan. 1982 (with notation of COE approval 23 Feb. 1982), DRD, OCE, Notebook: CERC Move, Vol. I.

43. Draft memorandum, "Possible CERC Move to WES," 2 Dec. 1981, DRD, OCE, Notebook: CERC Move, Vol. I. The tanks at Oregon State University and Offshore Technology Corporation, Escondido, California, both had spectral wave generators.

44. Interview with James Choromokos, Jr., OCE, 31 July 1985; *The CERCular*, Vol. CERC-84-

1, May 1984; *The Quarterly CERCular*, Vol. 7, No. 3, July 1982; interview with Robert W. Whalin, 18 and 22 August 1986.

45. Col. Ted E. Bishop, CERC, Memorandum for Director, Research and Development, "Proposed Move of Coastal Engineering to WES, 4 Dec. 1981, DRD, OCE, Notebook: CERC Move, Vol. I.

46. Interview with James Choromokos, Jr., 31 July 1985.

47. "Civilian Personnel Plan for Transfer of Function U.S. Army Coastal Engineering Research Center, no date with enclosures: Chief of Engineers Memorandum for Assistant Secretary of the Army (Civil Works), Subject: Relocation of Coastal Engineering Research Center (CERC), Kingman Complex, Fairfield County, VA, to the Waterways Experiment Station (WES), Vicksburg, MS, 10 Mar. 1982, DRD, OCE, Notebook: CERC Move, Vol. I; interview with James Choromokos, Jr., 31 July 1985.

48. Interview with Fred Camfield, 21 Aug. 1986. A hydraulic engineer at CERC since 1975 in the Coastal Design Criteria Branch and Evaluation Branch. Camfield later was appointed Chief of the Coastal Design Criteria Branch at CERC, effective Sept. 1982, and ultimately moved with CERC to Vicksburg where he later served as Acting Chief of the Engineering and Development Division. *The Quarterly CERCular*, Vol. 7, No. 4, Oct. 1982; *The CERCular*, Vol. CERC-84-1, May 1984.

49. Bishop to James Choromokos, 9 Mar. 1982; Marsh to Parris, 6 Apr. 1982, DRD, OCE, Notebook: CERC Move, Vol. I .

50. The Alexandria *Gazette*, 14 Apr. 1982; interview with James Choromokos, 31 July 1985.

51. The Fairfax *Journal*, 16 Apr. 1982.

52. Senator John W. Warner to Lt. Gen. J.K. Bratton, Chief of Engineers, 15 Apr. 1982, enclosing Camfield to Warner, 28 Mar. 1982. DRD, OCE, Notebook: CERC Move, Vol. I. Camfield had mailed his letter to Senator Warner as an afterthought after preparing information to send to his county supervisor.

53. Interview with James Choromokos, 31 July 1985.

54. The Fairfax *Journal*, 25 Jan. 1983; The Washington *Post*, 17 Dec. 1982; Realignment Fact Sheet, DRD, OCE, Notebook: CERC Move, Vol. I; The Fairfax *Journal*, 25 Jan. 1983.

55. The Fairfax *Journal*, 25 Jan. 1983.

56. The Washington *Post*, 29 Jan. 1983.

57. Realignment Fact Sheet, 15 Feb. 1983, DRD, OCE, Notebook: CERC Move, Vol. I.

58. The LWT had replaced a similar facility at Dalecarlia Reservoir and used the same old monochromatic wave generating mechanism, Navy surplus in 1953, whose drive converter had been updated in 1973 at a cost of approximately $80,000. Because research performed in the LWT had the lowest priority in the CERC R&D program, the wave generator had not been replaced.

59. Realignment Fact Sheet, 15 Feb. 1983, DRD, OCE, Notebook: CERC Move, Vol. I.

60. Informal DRD records indicated that 20 CERC employees made the transfer. Interview with William E. Roper, 18 July 1985. Fred Camfield counted 23 employees who moved. Further, as of Jan. 1985, of the people who transferred, two had resigned to enter Ph.D. programs, five had transferred or were promoted to other Corps or Army activities outside Mississippi (three people returned to Virginia), three became branch chiefs and one an acting branch chief at CERC, and one became a group chief in the Environmental Laboratory at WES. Of those who did not transfer, one later rejoined CERC at WES. Camfield to the authors, 2 Feb. 1988. The new CERC had impressive credentials. Of the 84 engineers and scientists, 24 had doctorates (29%), 32 had master's degrees (30%), and the remaining 28 had bachelor's degrees (33%). Of the 58 new hires, 32 were female or minority employees. Five of the nine high grade engineers and scientists were female. Seven of the 23 engineers and scientists at the grade of GS 12 and below, 12 of the 32 engineers, and 20 of the 26 non-scientist personnel were minority and/or female. The actual cost of the relocation was $1.275 million, some $167,000 less than originally estimated. Choromokos, Report No. 12, CERC Relocation to WES, 6 Sept. 1983; Col. Tilford C. Creel, Commander and Director, Resource Management Office, WES to Choromokos, 29 Feb. 1984, DRD, OCE, Notebook: CERC Move, Vol. I.

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